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The National Crop Loss Assessment Network (NCLAN) consists of a group of organizations cooperating in field work, crop modeling, and economic studies to assess the immediate and long-term consequences of air pollution on crop production. Two primary objectives are 1) to define relationships between yeilds of major agricultural crops and doses of ozone, sulfur dioxide, nitrogen dioxide, and mixtures of these pollutants under realistic field conditions and 2) to use these relationships to assess the consequences of these pollutants throughout the United States. The strategy for completing the economic assessment includes developing and extrapolating a comprehensive set of dose-response data for use in an economic model to estimate effects of crop yields changes on producers and consumers.

The regional economic assessments initiated in 1982 demonstrated the utility of the NCLAN response data. Results from these assessments in California and the Corn Belt states indicate that moderate reductions in ambient ozone levels (ca. 25% below the 1980 levels) yould yield substantial economic benefits to major agricultural areas of the United States. A preliminary national assessment model was then constructed and tested by expanding the regional model of the Corn Belt. This national assessment uses NCLAN response data generated through the 1983 field experiments.

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ABSTRACT

The National Crop Loss Assessment Network (NCLAN) consists of a group of organizations cooperating in field work, crop modeling, and economic studies to assess the immediate and long-term consequences of air pollution on crop production. Two primary objectives are 1) to define relationships between yields of major agricultural crops and doses of ozone (O_3), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), and mixtures of these pollutants under realistic field conditions and 2) to use these relationships to assess the consequences of exposure of economically important crops to ambient levels of these pollutants throughout the United States. The strategy for completing the economic assessment includes developing and extrapolating a comprehensive set of dose-response data for use in an economic model to estimate effects of crop yield changes on producers and consumers.

This is the fourth annual report of NCLAN, covering the period from 1 February 1983 to 31 January 1984. During this period, research progress has been made in understanding the interacting elements related to air pollution-induced crop loss and integrating them with the economic assessment effort. This was accomplished by generating information on O_3 dose-yield functions for winter wheat and lettuce; developing O_3 sensitivity ranking for soybean cultivars, comparing the O_3 dose-yield relationships for tobacco using different exposure regimes; assessing the yield response of soybean and winter wheat to mixtures of O_3 and SO_2; and evaluating the influence of soil moisture on dose-response relationships for soybean and barley. These and other NCLAN response data were critical inputs to the economic assessments undertaken in 1983.

Lettuce was severely injured by O_3 at concentrations above ambient; total head weight and weight of market-sized ("24") heads were reduced at 7-h per day seasonal mean O_3 concentrations >0.083 ppm. Reductions averaged 13% and 35% for total head weights and 21% and 80% for marketable heads from exposure of 7-h per day seasonal mean O_3 concentrations of 0.104 and 0.128 ppm, respectively (Shafter, CA).

The O_3 dose-response relationships for 'Abe' and 'Arthur-71' cultivars of winter wheat were similar; both cultivars exhibited smaller seeds which reduced yield. These cultivars were more sensitive to O_3 than was field corn or grain sorghum and less sensitive than soybean. Yields of four cultivars of soybean were reduced about equally by O_3. Yield losses predicted by a combined response model were 13, 17, and 30% at 0.05, 0.06, and 0.09 ppm, respectively, compared with a control of 0.025 ppm O_3 (Argonne, IL).

In three separate exposure regimes, tobacco ('McNair 94') was exposed to constant additions of nonfiltered (NF) air (0.02, 0.04, 0.06 ppm O_3) or proportional additions of NF air (1.3, 1.6, or 1.9 times ambient O_3) for 7-h or 12-h per day. At similar seasonal O_3 concentrations, both types of 7-h additions produced approximately the same decreases in tobacco yield. However, proportional 12-h per day additions caused a greater decrease than did either type of 7-h per day addition (Raleigh, NC).

Several experiments added to our understanding of the interaction between soil moisture stress and plant response to O_3. In 'Davis' soybean grown with adequate moisture, exposures to seasonal 7-hr per day mean concentrations of 0.076 and 0.100 ppm resulted in losses of seed yield of 20 and 29%, respectively, but under conditions of severely reduced soil moisture yields were not significantly affected by O_3 (Raleigh). In soybean cultivars 'Williams' and 'Corsoy', soil moisture stress reduced yield losses following exposure to 7-h per day seasonal means of 0.132 and 0.108 ppm O_3, but not at 0.079 ppm (Beltsville, MD). Exposure to a 7-h per day seasonal mean concentration of O_3 as high as 0.064 ppm had no effect on yield of barley cultivar 'CM-72' in normal or water-stressed plots, suggesting that O_3 concentrations in the Central Valley of California during the period from December through May 1983 were too low to affect growth and yield of barley (Shafter).

Possible interactive effects of O_3 and SO_2 were investigated for the winter wheat cultivar 'Vona' and soybean cultivars 'Corsoy-79' and 'Amsoy-71'. In winter wheat, exposure to a seasonal 7-h per day O_3 concentration of 0.096 ppm reduced head weight by about 50%, due primarily to a reduction in seed size. The rate of photosynthesis was also reduced about 50%. Sulfur dioxide concentrations of up to 0.363 ppm for 12 4-h exposures (3 per week) had no measurable effect on yield and no interactive effects of O_3 plus SO_2 on yield were found (Ithaca, NY). In soybean, there were significant effects of O_3, SO_2, and cultivar on seed yield, but there were no significant O_3 by SO_2 interactions on yield. Predicted losses were 12 and 42% at 0.06 ppm and 0.10 ppm O_3, respectively, when data were averaged across both cultivars and all SO_2 treatments. Sulfur dioxide-induced yield reductions were predicted to be 6.7% at 0.1 ppm, 17.4% at 0.3 ppm, and 32% at 0.6 ppm. Ozone-induced yield reductions were due to reduced individual seed weight and number, while SO_2-induced yield reductions were due primarily to reduced seed number (Argonne).

A simulation model, modified from one that estimates the response of yield to irrigation, was constructed to estimate the effect of moisture stress on yield losses induced by O_3. Assumptions regarding O_3 effects and O_3-moisture stress interactions were based on existing data and preliminary results from the O_3-moisture stress studies being conducted by NCLAN. Further research will be required to verify model assumptions and results, and estimate the model's sensitivity to various parameters (Corvallis, OR).

The regional economic assessments initiated in 1982 demonstrated the utility of the NCLAN response data. Results from these assessments in California and the Corn Belt states indicate that moderate reductions in ambient O_3 levels (*ca.* 25% below the 1980 levels) would yield substantial economic benefits to major agricultural areas of the U.S. A preliminary national assessment model was then constructed and tested by expanding the regional model of the Corn Belt. This national assessment uses NCLAN response data generated through the 1983 field experiments (Corvallis).

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SECTION I

INTRODUCTION

The current ozone (O_3) secondary National Ambient Air Quality Standards (NAAQS) is based, in part, on vegetation effects information presented in the Air Quality Criteria for Ozone and Other Photochemical Oxidants (US Environmental Protection Agency, 1978). The most current and indepth review for sulfur dioxide (SO_2) is found in the Air Quality Criteria for Sulfur Oxides (US Environmental Protection Agency, 1983). These reviews illustrated a need for additional field studies of the effects of exposure on economically important crops to support evaluation of the economic impact of O_3 and SO_2 on agriculture. The National Crop Loss Assessment Network was designed to fill some of the most important information gaps for crops.

The National Crop Loss Assessment Network (NCLAN) is a coordinated national program of field and laboratory studies, crop modeling, and economic assessment efforts initiated by EPA to address the significance of crop losses caused by air pollution and to aid in the establishment and justification of the secondary standards (NAAQS). The NCLAN research is directed toward understanding the biological effects of air pollution on crops in the ambient environment, and the economic significance of these relationships.

Thus far, the program has focused primarily on the effects of O_3 on agronomic crops, although some research has incorporated SO_2 with O_3 and a few studies were done with SO_2 and nitrogen dioxide (NO_2). However, no information has been generated on effects of O_3 on perennial plants, including ornamentals, fruits, and forest species.

A Research Management Committee (RMC), representing six air pollution research programs within the U.S. (Table 1.1.), plans, manages, and executes the NCLAN Research Plan (Preston, 1982). The program objectives, approach, and organization are discussed in detail elsewhere (Heck et al., 1981a, 1981b, Adams and Crocker, 1982; Heck et al., 1982a, 1982b; Kohut et al., 1982) and will be reviewed briefly.

The NCLAN program components (e.g., regional pollutant dose-yield response evaluations, pollutant/environmental interaction studies, physiological and growth studies, crop loss modeling, and economic modeling) have been coordinated to provide a systematic flow of information needed to conduct a national economic assessment of the effects of air pollutants on U.S. agriculture. A network of five field test sites (Ithaca, NY; Beltsville, MD; Raleigh, NC; Argonne, IL; Shafter, CA) have been established in four regions (Northeast, Southeast, Central States, Southwest) that contribute significantly to the production of major crops and have actual or potential pollution problems. At these test sites, normal crop cultural conditions are maintained under ambient and simulated air pollution regimes. In addition, crop modeling and economic assessment programs are situated in the Northwest at Corvallis, OR.

Thus far, the NCLAN field experiments have concentrated on completing O_3 dose-response data sets for the crop species of greatest economic importance. Data sets have been generated for barley, dry bean, corn,

Table 1.1. Site locations, regional coordinators, and senior scientists

	Site Location	Regional Coordinator	Senior Scientists
1.	Northeast Regional Crop Loss Assessment Program (NERCLAP)	Leonard Weinstein Boyce Thompson Institute Ithaca, NY	Robert G. Amundson Robert J. Kohut John A. Laurence
2.	Southeast Regional Crop Loss Assessment Program (SERCLAP)	Walter W. Heck, USDA North Carolina State Univ. Raleigh, NC	William W. Cure Allen S. Heagle John O. Rawlings
	Beltsville, Maryland		Timothy J. Gish Howard E. Heggestad
3.	Central States Regional Crop Loss Assessment Program (CSRCLAP)	Joseph E. Miller Argonne National Lab Argonne, IL	Lance W. Kress
4.	Southwest Regional Crop Loss Assessment Program (SWRCLAP)	O. Clifton Taylor University of California Riverside, CA	Patrick Temple
5.	Northwest Regional Crop Loss Assessment Program (NWRCLAP)	Eric M. Preston Environ. Prot. Agency Corvallis, OR	Richard M. Adams David A. King J. Miller Grady E. Neely David T. Tingey

cotton, grain sorghum, lettuce, peanut, soybean, tobacco, tomato and winter wheat. A few of these crops have been evaluated over two or more seasons, using several cultivars.

Table 1.2. lists the crops and cultivars on which the O_3 dose-response data are currently available from NCLAN. Though the O_3 dose-response data base is now substantial, past research in NCLAN (Table 1.3.) and elsewhere has shown that genetic and environmental factors may affect plant response. Extrapolation of the site-specific dose-response data to estimate regional level yield changes introduces a number of uncertainties which cannot yet be quantified. Many cultivars of each crop species may be grown in a region. The NCLAN dose-response data address from one to several cultivars for each crop. Potential extrapolation errors are introduced because the quantitative response of cultivars within a species may be different. The degree of difference in relative sensitivity among cultivars can be estimated experimentally. Thus far, this has been done in the field only for corn and soybean. However, because dose-response curves have been developed for several cultivars of soybean and wheat at different experimental sites in different growing seasons, a preliminary evaluation of the significance of between-year and among-cultivar response differences can be conducted for these crops. Use of the Weibull function for modeling dose-response permits development of combination models that incorporate inherent variations in species response among sites, years, and cultivars.

A second significant source of extrapolative uncertainty results from insufficent quantitative information describing how the dose-response to O_3 may be affected by changes in plant water status. Experiments with barley, cotton, and soybean have provided mixed results. The interaction of water stress with O_3 may be complex although it appears that sensitivity to O_3 is reduced under conditions of low soil moisture. Under conditions of moderate soil moisture stress and the presence of ambient O_3, some NCLAN results with soybean indicate that the effects of these two stresses on yield may be greater than additive. Substantial additional research will be required to fully define these relationships and employ them in NCLAN's economic assessments. Dose-response data for those crops that are not usually irrigated should be collected under several soil moisture regimes. These data would allow consideration of the potential impact of regional variations in soil moisture in the yield loss estimates. Accordingly, field and laboratory soil moisture studies are currently being conducted and will continue for the duration of the NCLAN program. This approach will allow the collection of appropriate data for the development of models to describe the effect of soil moisture on O_3 dose-response.

Other air pollutants may interact with O_3 to modify dose-response relationships, although the importance of these interactions to agriculture has not been fully elucidated. Experiments to date (Table 1.3.) suggest that these interactions may yield statistically significant results, but assessing their importance in affecting crop losses will require new techniques and additional experimentation.

Two important assumptions must be made in applying the biological data to the national economic assessment. 1) All economically important cultivars of species in aggregate respond similarly to those tested. 2) Environmental conditions differing from those in field experiments would

Table 1.2. Crops and cultivars for which NCLAN has developed O_3 dose-response data

Crop/Cultivar	% of Acreage in U.S.A.	Sites and Year Grown
Corn		Argonne, IL (1981)
Pioneer 3780	23	Argonne, IL (1981)
PAG 397		
Soybean		
Hodgson	20	Ithaca, NY (1981)
Davis		Raleigh, NC (1981, 1982, 1983)
Williams - 79		Beltsville, MD (1981, 1982, 1983) Argonne, IL (1983)
Essex		Beltsville, MD (1981)
Forrest		Beltsville, MD (1982)
Corsoy - 79		Argonne, IL (1980, 1983); Beltsville, MD (1983)
Amsoy - 71		Argonne, IL (1983)
Pella		Argonne, IL (1983)
Wheat	18	
Vona		Ithaca, NY (1982, 1983)
Arthur - 71		Argonne, IL (1982, 1983)
Abe		Argonne, IL (1982, 1983)
Roland		Argonne, IL (1982)
Cotton	4	
Acala SJ2		Shafter, CA (1981, 1982)
Stoneville 213		Raleigh, NC (1982)
Grain Sorghum	5	
A28+		Argonne, IL (1982)
Barley		
Poco	3	Shafter, CA (1982)
CM-72		Shafter, CA (1983)
Peanut		
NC-6	2	Raleigh, NC (1980)
Tomato		
Jet Star	<2	Beltsville, MD (1980)
Murietta		Tracy, CA (1981, 1982)
Kidney bean		
California Light Red	<1	Ithaca, NY (1980, 1982)
Tobacco		
McNair 994	<1	Raleigh, NC (1983)
Lettuce		
Empire	<1	Shafter, CA (1983)

Table 1.3. NCLAN field experiments related to interactions of genetic and environmental factors and O_3 dose-response

Crop/Cultivar	Year	Site
CULTIVAR SENSITIVITY RANKING		
Corn (14 hybrids)	1981	Argonne, IL
Soybean		
Williams-79, Pella, Corsoy-79, Amsoy-71	1983	Argonne, IL
INTERACTIONS: O_3 AND SOIL MOISTURE		
Cotton		
Acala SJ2	1981, 1982	Shafter, CA
Soybean		
Williams-79, Forrest	1982	Beltsville, MD
Williams-79, Corsoy-79	1983	Beltsville, MD
Davis	1983	Raleigh, NC
INTERACTIONS: O_3 AND SO_2		
Cotton		
Stoneville 213	1982	Raleigh, NC
Soybean		
Davis	1981	Raleigh, NC
Williams-79	1981, 1982	Beltsville, MD
Essex	1981	Beltsville, MD
Forrest	1982	Beltsville, MD
Amsoy-71	1983	Argonne, IL
Corsoy-79	1983	Argonne, IL
Tomato	1980	Beltsville, MD
	1981, 1982	Tracy, CA
Wheat		
Vona	1983	Ithaca, NY
OZONE EXPOSURE DYNAMICS		
Soybean		
Davis	1982	Raleigh, NC
Tobacco		
McNair 944	1983	Raleigh, NC

not significantly affect the aggregate estimate of plant response to O_3. The validity of these assumptions is being tested and preliminary results are presented.

This report presents results from 1983 research. The results include the biological dose-response data for O_3 and data concerning modification of these responses by environmental variables. In addition, the efforts to develop a soil moisture/O_3 model and the application of these data to an evaluation of the economic consequences of O_3 air pollution for U.S. agriculture are discussed.

SECTION 2

CONCLUSIONS

Lettuce Response to O_3 (Shafter, CA)

Exposure of head lettuce (cv. 'Empire') to O_3 during the fall growing season caused severe foliar injury on plants exposed to concentrations 1.7 or 2.0 times greater than ambient (seasonal mean 7-h/day O_3 concentrations of 0.104 and 0.128 ppm, respectively). These exposure levels also reduced total head weight 13% and 35%, respectively, compared with plants growing in charcoal-filtered air at 0.021 ppm. Marketable size ("24") head weight was reduced 21% and 80%, respectively, by the two treatments. No differences in stomatal conductance or transpiration were found among the different O_3 treatments. Data suggest that the threshold for yield reduction occurred above 0.083 ppm (seasonal 7-h O_3 mean).

Winter Wheat Response to O_3 (Argonne, IL)

Two cultivars of winter wheat ('Abe' and 'Arthur-71') were exposed daily to O_3 at seasonal means of 0.018, 0.044, 0.062, 0.078, 0.095 ppm to determine exposure-response relationships for yield and to compare these relationships with those observed in 1982. Analysis of data indicated significant O_3 effects on yield; the reductions in yield were due to decreases in individual seed weight. The yield responses to O_3 were not different for the two cultivars; however, their sensitivity was somewhat less in 1983 than in 1982. Ozone concentrations were higher in May of 1982 than in May of 1983 and foliar injury symptoms developed earlier in 1982 than in 1983. This earlier stress may be responsible for increased sensitivity in 1982. In 1982, the wheat may have been under moderate moisture stress and thus more sensitive to ambient O_3. Winter wheat ('Abe' and 'Arthur-71') is considered more sensitive to O_3 than is grain sorghum or field corn and less sensitive to O_3 than soybean.

Soybean Cultivars (4) Response to O_3 (Argonne, IL)

Plants of four soybean cultivars ('Corsoy-79', 'Amsoy-71', 'Williams-79', 'Pella') were grown in open-top chambers and exposed daily to O_3 at seasonal means of 0.022, 0.046, 0.071, 0.094 ppm. Data analyses indicated treatment and cultivar pair (group) effects on overall seed yield. At the highest O_3 exposure level, the yield reductions were due nearly equally to reductions in seed number and individual seed weight. The responses of the four cultivars to O_3 were not different from each other. The predictions of yield loss obtained from a combined Weibull model are nearly identical to the common model generated from nine previous NCLAN soybean data sets (six cultivars). Predicted yield reductions were 12.6% at 0.05 ppm O_3, 17.2% at 0.06 ppm, and 29.9% at 0.09 ppm O_3, compared to a control of 0.025 ppm O_3.

Effects of Exposure Dynamics on The Response of Tobacco to O_3 (Raleigh, NC)

'McNair 944' flue-cured tobacco was exposed to chronic doses of O_3 obtained by adding constant (0.02, 0.04, 0.06 ppm) or proportional (1.3, 1.6, or 1.9 x ambient O_3) O_3 additions for 7 h per day and proportional (1.3, 1.6, or 1.9 x ambient O_3) O_3 additions for 12 h per day. At similar seasonal O_3 concentrations, both types of 7-h additions produced similar decreases in tobacco yield. However, proportional 12-h additions caused greater yield decrease than did the proportional 7-h additions.

Effects of Soil Moisture on the Response of Soybean to O_3 (Raleigh, NC)

'Davis' soybeans were exposed to chronic exposures of O_3 in plots with adequate soil moisture or with severely limited soil moisture. Dose-response relationships using adequate soil moisture were similar to those in previous years with measured seed yield losses of 20 and 29% at seasonal 7-h per day means of 0.076 and 0.100 ppm, respectively. However, the O_3 effect was not significant for the severely water-stressed plants. The plot-to-plot variability in soybean yield was much greater among the soil moisture stress treatments than among plots with adequate soil moisture. This was probably due to greater effects of small plot-to-plot differences in soil moisture in the moisture-stressed plots than in the adequate moisture plots.

Effects of Soil Moisture on the Responses of Two Cultivars of Soybean to O_3 (Beltsville, MD)

Soybean cultivars 'Williams' and 'Corsoy' were exposed to six levels of O_3 each at two soil moisture levels, -0.05 megapascals (MPa) and -0.36 MPa. Water was either added by drip irrigation or withheld to maintain the desired soil water potentials in the primary root zone. However, roots had access to groundwater at greater depth (1.3 - 1.5 m). Differences in soil moisture changed the dose-response relationships in two ways depending upon the O_3 dose. At O_3 concentrations which were 60 and 90 ppb greater than in ambient air, soybeans yielded about 10% more under drought conditions than when soil moisture stress was avoided. At ambient O_3 concentrations, however, bean yields were reduced significantly more under drought conditions than when soil moisture stress was avoided. Apparently, the elimination of moisture stress enabled plants to tolerate ambient O_3 concentrations without a yield reduction. Plants of both cultivars, but especially Corsoy, when grown in charcoal-filtered air appeared to acclimate to a level of soil moisture stress which was very damaging to plants grown in ambient air. Under moist conditions, plants in the carbon-filtered (CF) and nonfiltered (NF) air treatments received about 60% more water than provided by normal rainfall, whereas under dry conditions they received only 35% of normal rainfall.

Effects of Soil Moisture on the Response of Winter-Season Barley to O_3 (Shafter, CA)

Barley cultivar 'CM-72' was exposed to six levels of O_3 in open-top chambers from February to May 1983. Treatment seasonal 7-h mean O_3 concentrations were 0.015 ppm, 0.030 ppm, 0.040 ppm, 0.047 ppm, 0.055 ppm, and 0.064 ppm and ambient was 0.030 ppm. Half the plots received normal levels of irrigation and half received 36% less total water (irrigation + precipitation). Yield of barley was reduced 24% in water-stressed ambient air plots and 11% in water-stressed chamber plots compared with those given normal irrigation. Exposure to O_3 as high as 0.064 (seasonal 7-h mean) had no effect on yield either in normal or water-stressed plots.

These results are similar to those obtained during the previous winter/spring growing season in which a different cultivar of barley, 'Poco', was used. Although these results cannot be extrapolated to include years in which O_3 concentrations are significantly higher than those encountered in the previous two years, they suggest that O_3 concentrations during the winter/spring growing season in the Central Valley of California were too low to affect the growth of spring barley.

Winter Wheat Response to O_3 and SO_2 (Ithaca, NY)

The winter wheat cultivar 'Vona' was exposed to four levels of both O_3 and SO_2 to assess pollutant effects on growth, physiology, and yield. Proportional control of O_3 produced seasonal 7-h treatment levels of 0.027, 0.054, 0.076, and 0.096 ppm. Sulfur dioxide exposures were 4 hours in duration, 3 days a week, and at concentrations of 0.0, 0.039, 0.166, and 0.363 ppm. Both O_3 and SO_2 reduced stomatal conductance although no interactive effects were found. Photosynthesis was reduced with increasing concentrations of O_3. The photosynthetic rate of plants exposed to 0.096 ppm O_3 was approximately 50% of that of plants receiving 0.027 ppm. A similar reduction was found for the head weight of plants in the highest O_3 treatment. Yield losses due to O_3 were not as great in 1983 as they had been in 1982. This could be partly the result of the shorter exposure period or reduced precipitation in 1983. The dose-response curve for yield was similar to that found for other wheat cultivars in NCLAN although losses for Vona were greater than for the others. Sulfur dioxide had no effect on yield and no SO_2/O_3 interactive effects were found. Ozone appeared to reduce seed size rather than seed number.

Soybean Response to O_3 and SO_2 (Argonne, IL)

Plants of two soybean cultivars ('Corsoy-79', 'Amsoy-71') were exposed to O_3 (7-h/day seasonal mean) and/or SO_2 stress superimposed on a regional O_3 stress. The experiment was unreplicated and used four levels of O_3 (0.023, 0.046, 0.066, 0.092 ppm) and four of SO_2 (0.017, 0.089, 0.295, 0.564 ppm). Analyses of seed yield data indicated significant O_3, SO_2, and cultivar effects. There was no significant interaction between O_3 and SO_2. The cultivars did not differ in their responses to O_3 or SO_2. Losses predicted from regression models for both cultivars and all SO_2 treatments were 12% at 0.06 ppm O_3 and 42% at 0.10 ppm O_3. SO_2-induced yield reductions were predicted to be 6.7% at 0.1 ppm, 17.4% at 0.3 ppm, and 32% at 0.6 ppm. Ozone-induced yield reductions were due to reduced individual seed weight and number, while SO_2-induced yield reductions were due primarily to reduced seed number.

Quality Assurance

All NCLAN sites received a field review by the Project Quality Assurance Officer during which a systems evaluation of procedures for dispensing and monitoring air pollutants was made. During the same visit, a systems evaluation of procedures for the implementation of the biological quality assurance plan was made. If deficiencies were noted in either area, corrective action was either taken immediately or a plan for action was developed. A performance audit of air monitoring instruments at each NCLAN site was conducted by Research Triangle Institute. All operational instruments audited were found to have accuracy classification of either excellent or satisfactory; all instruments met expected performance standards.

Time-Share Monitoring

Studies were conducted at two NCLAN sites to evaluate the adequacy of time-share monitoring for characterizing the hourly and 7-h O_3 treatment concentrations. Observation rates of from 1 to 30 per hour were compared. The studies indicated that multiple-day 7-h averages could be determined as accurately with one or two observations per hour as they could with 15 or 30 observations per hour. The maximum 1-h and 7-h values could be accurately determined with two or three observations per hour. In summary, the O_3 data collected by NCLAN with time-shared monitoring accurately characterizes the exposures and treatment levels in the studies.

Modeling The Effects of Drought on Crop Loss Due to O_3 (Corvallis, OR)

A model was constructed to assess the effect of drought in modifying O_3-induced crop losses. The model predicts O_3 injury, as mitigated by drought, throughout the season and also estimates the impact of previous O_3 injury on soil water use as the season progresses. The model is based on a published model that estimates the response of yield to irrigation and incorporates assumptions regarding O_3 effects and O_3/drought interactions based on published results and preliminary results from the NCLAN O_3 x water stress study.

The O_3 x water stress model predicts a decline in O_3-induced crop loss due to naturally occurring drought. Model runs with midwestern rainfall inputs indicate that drought often affects crop sensitivity to O_3. For a given drought effect on yield, the modeled sensitivity of crops to O_3 varies somewhat, apparently due to variation in the timing of rainfall. These results are appropriate for soybeans or for crops with a water use pattern similar to soybeans. Similar model results are expected for other water-limited crops unless model assumptions regarding O_3 and drought interactions are altered for different crops.

Crop Loss and Economic Assessment (Corvallis, OR)

Two major objectives of the economics program in 1983 were to complete the series of regional economic assessments initiated in 1982 and to implement a national-level economic model of agriculture for use in the 1984 preliminary assessment. Both of these objectives were achieved.

The regional assessments tested alternative economic methodologies and provided estimates of the effects of alternative ozone levels on agriculture in California, Illinois, and the Corn Belt region (Ohio, Illinois, Indiana, Iowa, and Missouri). A number of economic methodologies were found to be tractable at the regional level, but the mathematical programming-based assessment procedure is most appropriate for national assessments given the nature of the problem and the type of data available at the national level. A "duality" micro theoretic study in Illinois, based on yield and input data collected directly from producers, demonstrated the importance of linking biological and behavioral data. In a programming-based assessment in the Corn Belt, moderate reduction in O_3

(25% below 1980 ambient levels) in that region results in benefits to society of approximately $700 million. A national assessment model was constructed by expanding the regional programming model used in the Corn Belt assessment. This procedure makes efficient use of the available NCLAN response data and allows for the projection of economic effects under a range of O_3 levels. The national model was successfully validated against 1980 actual values of prices, quantities and revenues.

SECTION 3

RECOMMENDATIONS

The results of NCLAN research illustrates the need to better understand the influence of selected biotic and abiotic variables on the O_3 dose-response relationships for the crops studied. Factors that are considered to be important include soil moisture status, exposure dynamics, cultivar variability, other pollutants, and insects and diseases. Assessment of the influence of these variables on O_3 dose-response functions will increase the accuracy of and confidence in the regional and national crop loss estimates and the economic assessments. To achieve these important additions to our understanding of dose-response relationships and economic analyses, the following recommendations for priority research are made.

1) Development of O_3 dose-response relationships for hay crops should continue. After completion of these hay crop studies, species accounting for approximately 95% of the U.S. field crop acreage will have been evaluated in NCLAN.

2) It is important to elucidate the effects of soil moisture stress on yield response to O_3. These effects will be incorporated into dose-response functions and employed in the economic loss assessment. The soil moisture stress studies should be conducted in the field using rainfall exclusion systems to allow accurate control of soil moisture. The studies may start with two soil moisture levels but eventually at least three at least three should be included. The energy status of the water in the primary root zone should be monitored.

3) The development of biological data synthesis and extrapolation from the NCLAN data base needs to be a continuing effort. This permits new models and concepts for making regional/national assessments to be tested and eventually, if better, incorporated into the assessment efforts.

4) The exposure dynamics of the field experimental designs requires calibration as the NCLAN program moves from 7-h constant O_3 additions to 12-h proportional additions. This is a critical component that will provide a melding of the two types of data. The program has made only one comparison to date - tobacco, in this report.

5) The scope of the national economic model should be expanded to accommodate a wide range of O_3-yield related issues. Alternative moisture stress scenarios and a less time-specific base model will increase the generality of the model for use in the 1986 assessment. Other issues, such as the effects of O_3 on yield variability, have important economic implications and should be tested and, if significant, incorporated in the economic model.

6) Additional refinements to the crop loss modeling effort should be explored. To the extent feasible, methodologies used in large area crop production forecasting should be incorporated into the models.

7) The influence of various components of the O_3 exposure regime (e.g., concentration, exposure duration, and exposure frequency) on plant response should be evaluated to allow pollutant exposure to be more clearly related to effect. Assessing exposure and dose characterizations and their relationships to yield losses will provide important information for setting secondary air quality standards.

8) Experiments to evaluate the effects of SO_2 exposure on O_3 dose-response functions should continue (through funding from the Electric Power Research Institute). More research is needed on the influence of NO_2 on these responses.

9) Cultivar screening to evaluate the degree of variability within a crop species should continue. These assessments would allow additional refinement of the crop loss and economic assessments.

10) Pollutant/pest interactions should be evaluated to assess the potential roles of air pollutants in altering disease epidemiology and insect population dynamics. Modification of insect and disease-induced crop losses by air pollutants could have significant national economic consequences.

11) Research on the effects of O_3 on yields of perennial crops such as grapes and apples and on the growth and marketability of ornamentals should be initiated. These crops are of considerable economic importance in their production areas and the regional consequences of pollutant-induced losses could be significant.

The priority areas recommended for continuation in 1985 include items one through eight from the above listing.

Table 3.1. Summary of 1984 NCLAN field experiments

Location	Design	Species Cultivars
Northeast		
Ithaca, NY	O_3 - SO_2, Physiology and Yield	Red Clover, Arlington/ Timothy Champlain
Southeast		
Raleigh, NC	O_3 - Soil Moisture	Soybean, Davis
	O_3 - Soil Moisture (Physiology and Yield)	Ladino clover, Regal Tall fescue, Kentucky 31
Central States		
Argonne, IL	O_3 - SO_2	Alfalfa, WL-312
Southwest		
Shafter, CA	O_3 - Soil Moisture	Alfalfa, WL-514

SECTION 4

RESPONSE OF CROPS TO OZONE

4.1. OZONE DOSE-RESPONSE RELATIONSHIPS

4.1.1. Response of Head Lettuce to O_3 (SWRCLAP) (P. J. Temple, O. C. Taylor, L. F. Benoit, C. A. Reagan, R. W. Lennox).

4.1.1.1. Introduction

Lettuce (*Lactuca sativa* L.) was among the first species identified as being highly susceptible to oxidant injury in Southern California. Since those early observations in the 1940's, oxidant injury symptoms have been observed on field-grown lettuce cultivars in many parts of California, and foliar injury has occasionally been so severe as to render the crop unmarketable or greatly reduce its commercial value. Generally this has been considered an effect of PAN. Despite its obvious susceptibility to foliar injury, relatively little is known about the long- term effects of ozone (O_3) on growth and yield of lettuce. A preliminary open-top chamber experiment conducted in 1980 suggested that lettuce yield could be reduced at elevated concentrations of O_3, but no dose-response functions could be derived from this study. California leads the nation in the production of lettuce with 72% of the U.S. market in 1979. Total value of the California lettuce crop exceeded $369 million. Lettuce is grown year-round in Southern California, and fall production is concentrated in areas of potentially elevated ambient O_3 such as the Southern San Joaquin Valley. The objective of this experiment was to develop a dose-response function for the effects of O_3 on growth and yield of head lettuce.

4.1.1.2. Materials and methods

Crop establishment and irrigation. The field used in these experiments was the same field used in previous NCLAN experiments at the USDA Cotton Research Station in Shafter, CA. A cover crop of cowpeas (*Vigna sinensis* L.) was rototilled into the plot area to a depth of 30 cm on 30 July 1983. Superphosphate (0-25-0-10S) was spread evenly over the field at a rate of 140 kgP/ha and the area was treated with Balan (pre-emergence herbicide) at a rate of 7 L/ha. Plots were fertilized with 36 kg/ha of nitrate (20-10-10) and four flat-topped beds each 5.16 m long and 56 cm wide were formed on 100-cm centers in each of 30 plots. Two rows of crisp-head lettuce (L. *sativa* var *capitata* cv 'Empire') were seeded 30.5 cm apart on each bed on 16 August. The site was sprinkle-irrigated on 18 August and later as needed until seedling emergence. Plants were thinned or transplanted as needed to obtain a uniform stand of 5-6 plants per meter-row. Details of pest control treatments are listed in Table 4.1.1.1.

Irrometers were installed in each plot at 30 cm depth. Irrigation water was applied before soil moisture reached -300 mb and before furrow bottoms became completely dry. Plots were furrow-irrigated through a manifold system that delivered approximately 1 ha-cm of water per hour. All plots received the same amount of irrigation throughout the season. Total precipitation plus irrigation amounted to 58.4 cm of water for the season.

Table 4.1.1.1. Chronology of significant events in growth of 'Empire' head lettuce at Shafter, CA 1983

Month	Day	Event
July	30	Superphosphate applied (140 kgP/ha) Pre-emergence herbicide (Balan) applied
Aug	16	'Empire' lettuce seeded on false-furrow double beds
	18	Sprinkle-irrigation begun until full emergence
	24-31	Plants thinned or transplanted to 5-6 per m-row
	31	Chambers in place; O_3 monitoring begun
Sept	1	Plants treated with Orthene (1.5 kg/ha), Thuricide (4.9 l/ha), and Sevin (79 ml/ha) weekly to control lepidopteran larvae
	6	O_3 additions began
	7	O_3 injury symptoms noted in NF x 2.0 chambers
	12	O_3 injury noted in NF x 1.7 chambers
	20	Head formation began in CF and NF chambers
Oct	10-15	Head formation in O_3-added treatments
	20	Heads in non-O_3 added chambers mature
	28	Last day of O_3 additions
Nov	3	Harvest of all treatments

Ozone treatments and monitoring. Seven O_3 treatments, each replicated four times, were assigned to 28 plots in a completely random experimental design, and 24 open-top chambers were placed on the lettuce plots on 31 August, when plants were at the 1-2 true leaf stage. Blowers were operated by time clock and ran from 0600 to 2000 daily. The six chamber treatments were charcoal-filtered (CF); half-filtered (NF x 0.50); non filtered (NF); and three treatments in which O_3 was added in proportion to ambient O_3 concentrations: NF x 1.3, NF x 1.7, and NF x 2.0. The four chamberless plots were used as ambient air (AA) controls. Ozone was added from 0900 to 1600 (PST) daily from 6 September until 28 October 1983. Ozone dispensing and monitoring, and data acquisition systems were the same as those used in previous NCLAN experiments. All NCLAN quality assurance protocols regarding instrument calibration and line loss measurements were made at prescribed intervals. Line losses average <2%, with maximum line loss <5%.

Plant growth and development. Lettuce seedlings emerged on 22 August, and plants were at the 1-2 true leaf stage when chambers were put in place on 31 August. Chambers and AA plots were systematically examined for pests, diseases, O_3 injury symptoms and plant development during the exposure. Measurements of stomatal conductance and transpiration were taken on five plants in every treatment on 11 and 12 October with a LI-1600, Steady State Porometer Licor Inc., Lincoln, NB.).

Harvest procedures and data analysis. Chambers and AA plots were harvested on 3 November. Separate 1-m row samples were taken from each of four quadrants in the chamber or AA plot. Each plant was cut at ground level, weighed, trimmed of wrapper leaves, and re-weighed. Size and quality of each head was also recorded. Commercial size heads were graded for quality by a state agricultural inspector, and weights were taken on composite "24"-head (commercial size) boxes from each O_3 treatment. All samples were collected and weighed in accordance with NCLAN quality assurance protocols for the processing of biological samples.

Yield data were analyzed by analysis of variance using a completely randomized design. Dose-response relationships between seasonal 7-h O_3 means and harvest data for each treatment were analyzed by linear multiple regression and non-linear regression using the Weibull model. Open (AA) plots were not included in the regression analysis.

4.1.1.3. Results

Air quality. Seasonal 7-h (0900-1600) ambient O_3 concentration averaged 0.054 ppm during the exposure period for lettuce, 6 September to 28 October 1983. Seasonal fluctuations in 7- and 24-h ambient O_3 concentrations are shown in Figure 4.1.1.1. Mean seasonal 7-h O_3 concentrations for the six chamber treatments were: CF = 0.021 ppm; NF x 0.5 = 0.038 ppm; NF = 0.052 ppm; NF x 1.3 = 0.083 ppm; NF x 1.7 = 0.104 ppm; NF x 2.0 = 0.128 ppm. Mean seasonal diurnal curves for these treatments are shown in Figure 4.1.1.2. Other expressions of O_3 exposure, including highest 1-h concentration, highest 7-h concentration, and mean daily maximum hourly concentration, are given in Table 4.1.1.2.

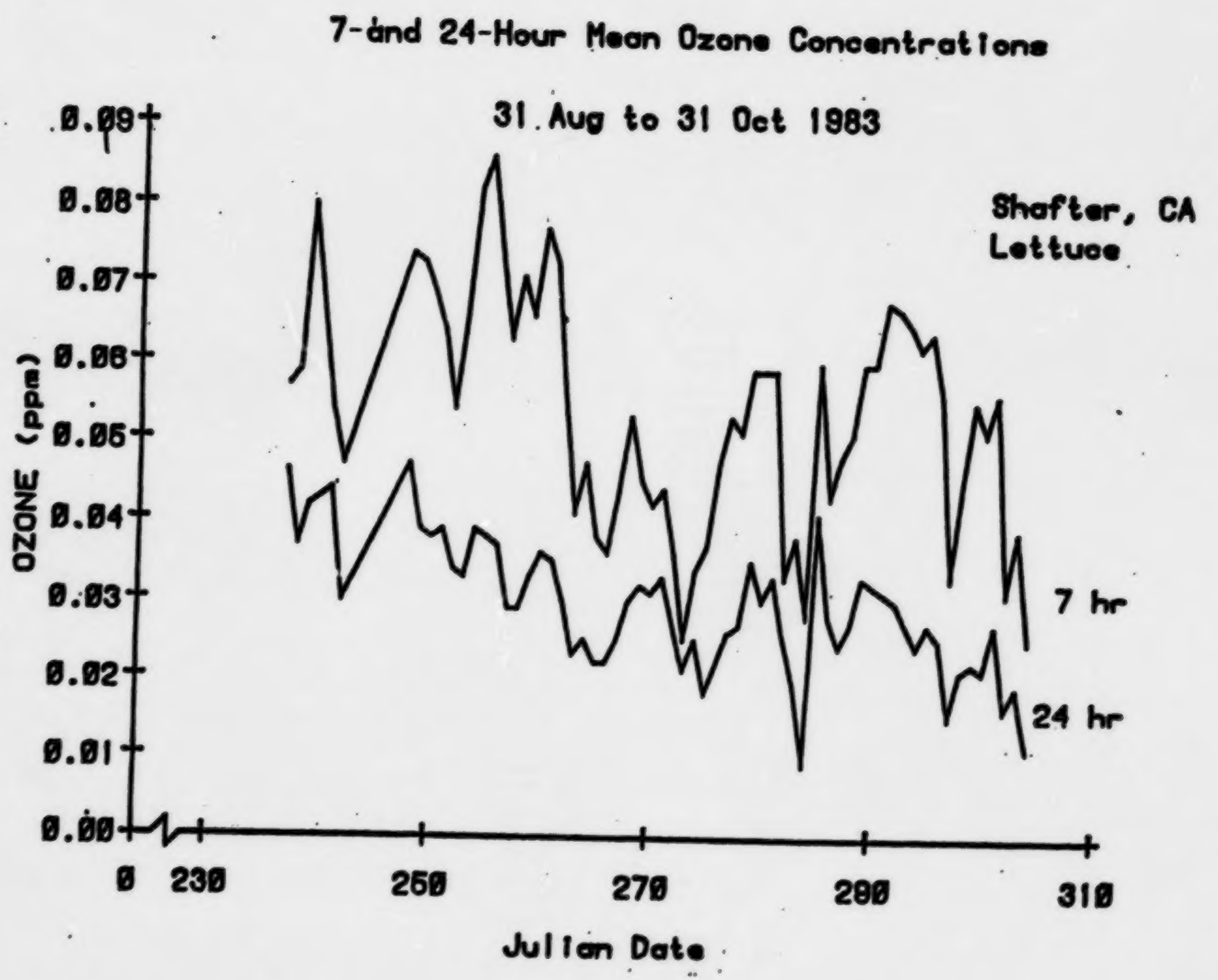

Figure 4.1.1.1. Daily 7- and 24-h mean ambient O_3 concentration during lettuce season, 31 Aug to 31 Oct 1983.

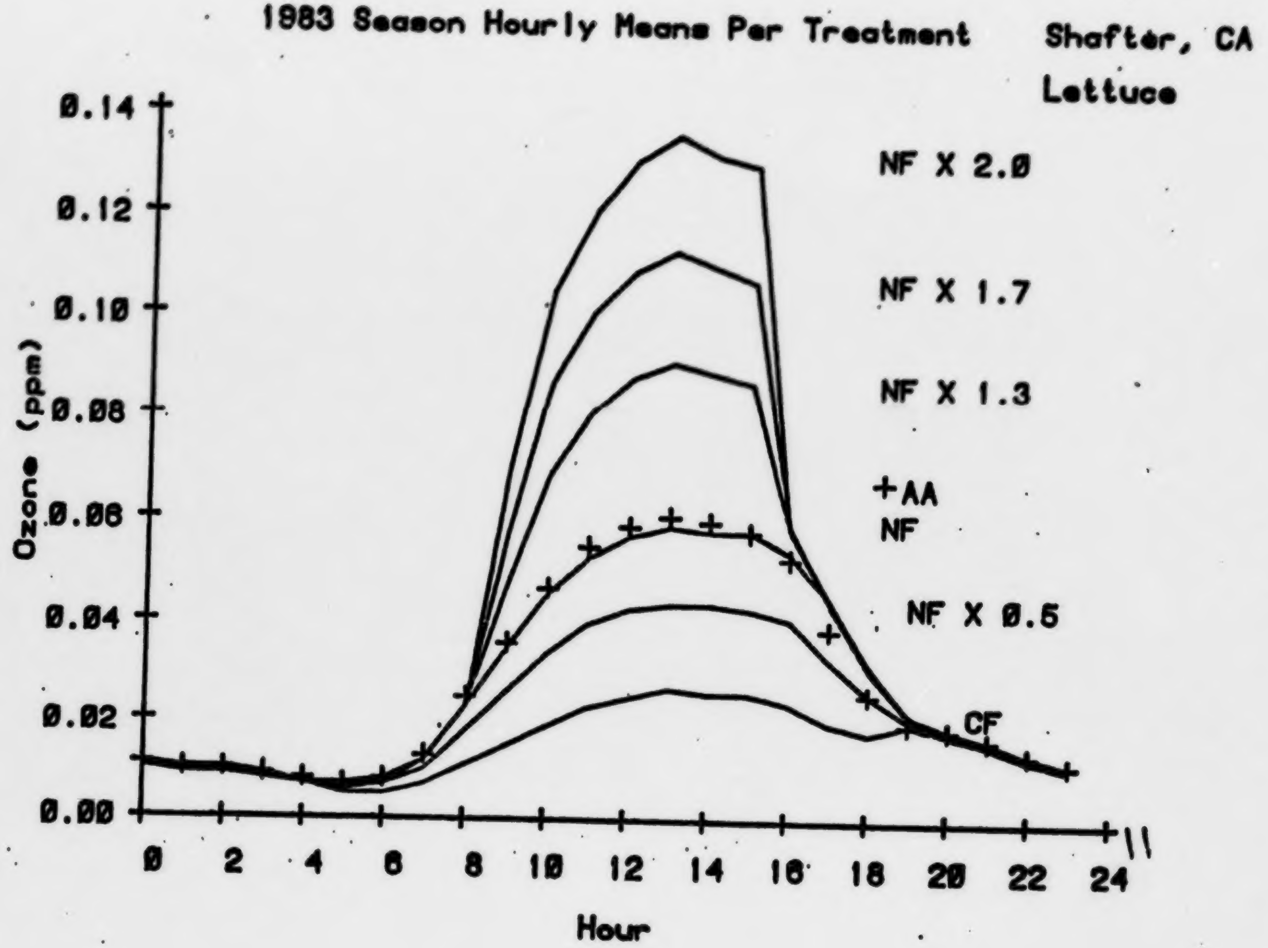

Figure 4.1.1.2. Diurnal curves of mean hourly O_3 concentrations for each lettuce treatment, 31 Aug to 31 Oct 1983; non filtered (NF), ambient air (AA), charcoal filtered (CF); the AA (+) and NF follow about the same curve.

Table 4.1.1.2. Summary of O_3 concentrations during exposure of 'Empire' lettuce at Shafter, CA, 6 Sept to 28 Oct 1983; all data in ppm

	7-h Means (0900-1600)		1-h Means		
Treatment*	Seasonal	Maximum	Maximum	Second Maximum	Seasonal
CF	0.021	0.034	0.047	0.040	0.027
NF x 0.5	0.038	0.059	0.066	0.065	0.046
NF	0.052	0.083	0.092	0.090	0.062
NF x 1.3	0.083	0.136	0.157	0.148	0.102
NF x 1.7	0.104	0.172	0.197	0.190	0.128
NF x 2.0	0.128	0.205	0.230	0.216	0.157
AA	0.054	0.086	0.095	0.093	0.065

*charcoal filtered (CF), non filtered (NF), ambient air (AA)

Plant responses. On 7 September, after two days of O_3 additions, slight interveinal chlorosis and bronzing were noted in the NF x 2.0 treatments. Similar symptoms were observed in NF x 1.3 and NF x 1.7 treatments by 12 September and symptom development increased in intensity with increasing exposure to O_3. No O_3 injury symptoms were observed in NF or AA treatments. Plants in NF x 2.0 chambers became severely reduced in growth and leaves appeared more elongated than those in other treatments. Head formation in NF x 2.0 chambers were delayed 2-3 weeks in comparison with CF and NF chambers.

Measurements of stomatal conductance and transpiration taken on 11 and 12 October showed no significant differences among treatments (Table 4.1.1.3.), although plants in CF and NF x 2.0 had lower conductances and rates of transpiration and AA plants had greater rates than other treatments.

Total head weight and weight and number of marketable ("24"-size) lettuce heads per treatment are given in Table 4.1.1.4. Ozone reduced total head weight and number of marketable heads in the NF x 1.7 and NF x 2.0 treatments; that is, when seasonal 7-h O_3 concentration exceeded 0.080 ppm. Biomass was reduced 12.9% in the NF x 1.7 treatment and 34.9% in the NF x 2.0 treatments, compared with CF chambers. Number of marketable heads was reduced 20.9% and 80.1%, respectively.

Analysis of variance of yield data indicated that position x O_3 interaction was not statistically significant, so sub-samples were summed for final data analysis. Total head weight and mean head weight from AA plots averaged 3% greater than NF chambers, but marketable head weight was 15% less in NF chambers compared with AA plots. Ozone effect on yield was highly statistically significant (Table 4.1.1.5.).

Regression analysis of yield data indicated that the least squares best fit model of yield responses to mean seasonal 7-h O_3 concentrations was piece-wise linear regression. However, the slope of the yield response curve below the break point of 0.083 ppm did not differ significantly from 0. Thus, the linear regression models for total head weight and marketable head weight were "plateau-linear" (Table 4.1.1.6.). The threshold for significant reduction in lettuce yield was at a mean seasonal 7-h O_3 concentration of 0.083 ppm. The Weibull model was also fit to these data. The response curve generated by fitting the Weibull model was similar to that of the plateau-linear model (Figure 4.1.1.3.). Estimates of Weibull parameters and their standard errors are given in Table 4.1.1.6.

4.1.1.4. Conclusions

Exposure of head lettuce (cv 'Empire') to proportional increments of O_3 during the fall growing season of 1983 indicated that severe foliar injury developed on plants exposed to O_3 concentrations 1.7 or 2.0 X greater than ambient, corresponding to seasonal 7-h means of 0.104 ppm and 0.128 ppm, respectively. These exposure levels also reduced total head weight 13% and 35%, respectively, compared with plants growing in charcoal-filtered air. Marketable size ("24") head weight was reduced 21% and 80%, respectively, and head formation was delayed 2-3 weeks. No differences in stomatal conductance or transpiration were found among the

Table 4.1.1.3. Mean abaxial stomatal conductance and transpiration of 'Empire' lettuce exposed to O_3 in open-top chambers, Shafter, CA, 10-11 Oct 1983.*

Ozone** Conc (ppm)	Stomatal Conductance (cm/s)	Transpiration (µg H_2O cm/s)
0.021	0.44	5.92
0.038	0.51	7.52
0.052	0.53	7.02
0.083	0.54	7.27
0.104	0.58	7.57
0.128	0.47	6.32
0.054	0.58	8.10

*Means of five plants per chamber or plot, four chambers per treatment

**Seasonal 7-h mean

Table 4.1.1.4. Yield data for field-grown 'Empire' head lettuce exposed to O_3 in open-top chambers in Shafter, CA from 6 Sept to 28 Oct 1983*

Ozone[††] Conc (ppm)	Total Head Weight (g/m-row)	Mean Head Weight (g)	No. "24"** Heads/plot	Weight "24" Heads/m-row	No. "24" Boxes[†]
0.021	6961	732	12	3037	2.0
0.038	7118	764	12	3072	2.0
0.052	7230	815	13	3210	2.2
0.083	7505	847	12.5	3383	2.1
0.104	6063	663	9.5	2402	1.6
0.128	4533	466	2.5	604	0.4
0.054***	7467	829	13	3780	2.2

*Four replicates per treatment

**Size "24" heads are commercial, marketable size.

***Ambient air plots.

[†] Mean number of boxes of size "24" heads per treatment.

[††] Seasonal 7-h mean

Table 4.1.1.5. Analysis of variance mean squares for 'Empire' lettuce exposed to O_3 in open-top chambers at Shafter, CA, 1983

Source of Variation	d.f.	Total Head Weight x 10^5	Weight per Head x 10^3	Weight of "24" Heads x 10^5	Number of "24" Heads
Ozone	5	49.36***	76.15***	41.97**	64.00**
Error	18	3.51	4.32	7.29	13.47
C.V.		9.0%	9.2%	33.1%	35.8%

Table 4.1.1.6. Best-fit regression equations for total head weight and "24" size (commercial) head weight of 'Empire' lettuce exposed to O_3 in open-top chambers, Shafter, CA, Aug to Oct 1983*

A. Plateau-Linear Model

Total Head Weight

$Y = 7203 - b_1[65616\ (O_3 - 0.082)]$ $R^2 = 0.78$

S.E. = ± 138 ± 9263

Weight of "24"-Size Heads

$Y = 3113 - b_1[62682\ (O_3 - 0.082)]$ $R^2 = 0.62$

S.E. = ± 189 ± 13103

if $O_3 < 0.082$; $b_1 = 0$

if $O_3 > 0.082$; $b_1 = 1$

B. Weibull Model

Total Head Weight

$Y = 7205.3 \exp [-(O_3/0.144)^{6.219}]$

S.E.: $\alpha = \pm 175.4$
$\sigma = \pm 0.0067$
$C = \pm 1.876$

Weight of "24"-Size Heads

$Y = 3187 \exp [-(O_3/0.122)^{8.837}]$

S.E.: $\alpha = \pm 239.4$
$\sigma = \pm 0.0056$
$C = \pm 4.283$

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*Y = g m-row^{-1}; X = mean seasonal 7-h/3 day O_3 concentration.

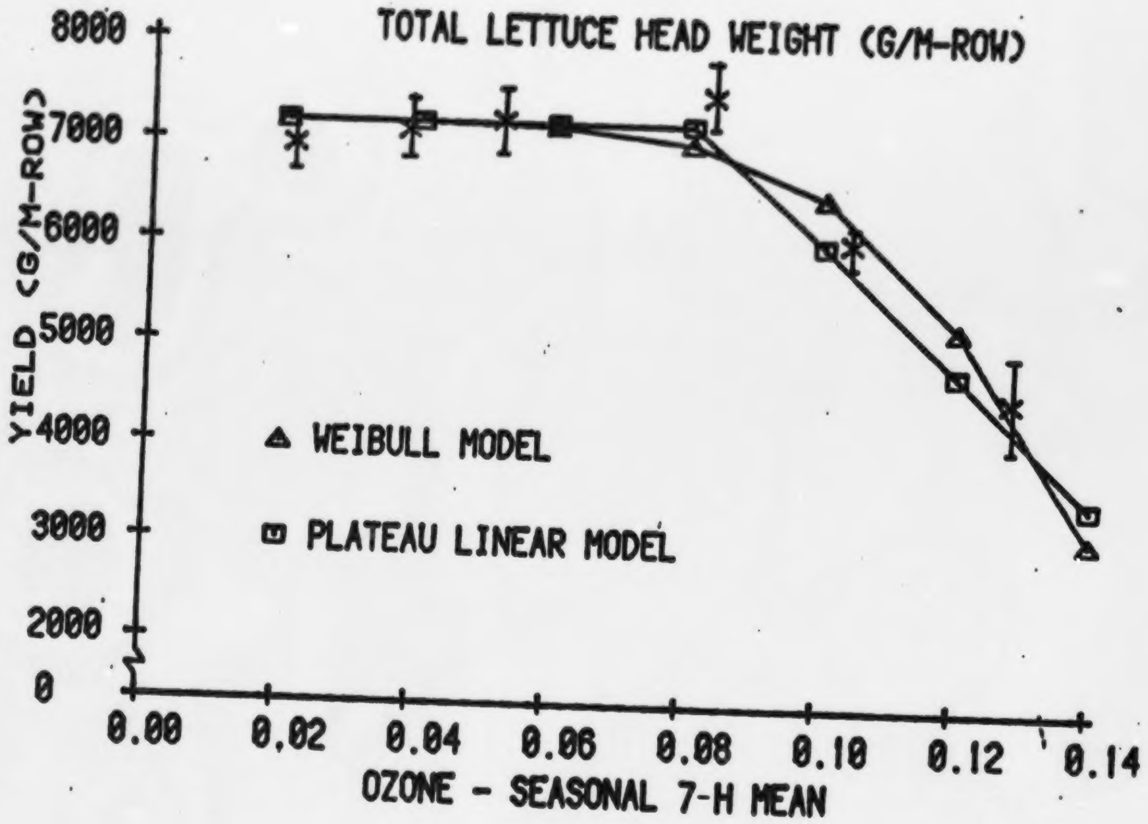

Figure 4.1.1.3. Dose-response curves of total head weight of 'Empire' lettuce to O_3. Data points (x) are mean treatment yields ± 1 standard error; ⊡ - the fitted plateau-linear model; △ - the fitted Weibull model.

different O_3 treatments. Regression analysis of yield data indicated that the threshold for yield reduction occurred above 0.083 ppm (seasonal 7-h O_3 mean).

4.1.2. Impact of O_3 on Winter Wheat Yield (CSRCLAP)--Lance W. Kress and J. E. Miller

4.1.2.1. Introduction

Wheat has been among the top four U.S. crops in terms of acreage planted and dollar value since 1960. Previous work with four cultivars of soft red winter wheat exposed to O_3 in open-top chambers indicated that yields were reduced from 1-11% at 0.06 ppm O_3 (seasonal 7-h/day mean) and 11-25% at 0.10 ppm O_3 compared to a 0.03 ppm control treatment (Heagle et al., 1979). The 1982 results at Argonne with three different soft red winter wheat cultivars produced loss estimates of 10-25% at 0.06 ppm O_3 and 32-53% at 0.10 ppm O_3 (Heck et al., 1984b).

The present study was initiated to establish relationships between yield of two important cultivars of soft red winter wheat (both examined in 1982) grown in the Midwest and chronic exposures to a range of O_3 concentrations.

4.1.2.2. Materials and Methods

Many of the important events regarding the experiment have been listed in Table 4.1.2.1. Seed of two winter wheat cultivars (*Triticum aestivum* L., 'Abe' and 'Arthur-71') were sown at a predicted rate of 40 seeds/m row in October, 1982 in 2.7 m x 3.5 m plots. Eight 3.5-m rows of 'Abe' were spaced 18 cm apart on the east half of each plot and eight rows of 'Arthur-71' were on the west half. The soil is a Morley silt loam (fine, illitic, mesic, Typic, Hapludalf), upland timber soil. This soil has a high water holding capacity, low permeability, pH of 6.1 ± 0.4, and 50,000 ± 11,000 kg/ha organic matter. In the spring of 1982, this part of the field had received 112 kg/ha K and was planted to alfalfa. The alfalfa was plowed down in September and the field received 20 kg/ha N, 80 kg/ha P, and 80 kg/ha K before the wheat was planted. In May the plots were top-dressed with 45 kg/ha N. Irrigation was not necessary due to excessive rainfall in May and June (25.8 cm).

The experiment consisted of a split-plot experimental design with the whole plot treatments (ozone levels) arranged in a randomized complete block design with three replications. The six whole plot treatments were:

AA, no chamber (ambient air);

CF, charcoal-filtered air chambers;

NF, nonfiltered air chamber with a small amount of O_3 added to provide a concentration approximating that in the AA plot; and

NF + 0.02, NF + 0.04, and NF + 0.06, nonfiltered air with O_3 added to 0.02, 0.04, and 0.06 ppm above ambient, respectively.

Table 4.1.2.1. Dates for important events during the 1983 studies to determine the effect of O_3 on yield of winter wheat at Argonne, IL

Month	Day	Event
October 1982	8	Planted 'Abe' and 'Arthur-71' wheat
April 1983	27	0.89 cm rain
	30	1.42 cm rain
May	1	4.57 cm rain
	2	0.18 cm rain
	5	0.25 cm rain
	6	Panels installed on chambers, fans on - (0.05 cm rain)
	7	0.91 cm rain
	7	Calibrated O_3 sample lines @ 0.25 ppm O_3
	8	Began O_3 dispensing. Plants in 3-4 leaf stage and 20-40 cm in height
	9	Light frost on ground and plants - no injury developed
	10	Fertilized plots with 45 Kg/ha N (NH_3NO_3)
	12	Rain - no PM dispensing - (trace)
	13	Adjusted sample line inlet heights - (4.19 cm rain)
	14	Rain - no PM dispensing - (0.64 cm rain)
	15	Random sample line calibration checks
	16	0.15 cm rain
	17	0.03 cm rain
	18	Adjusted sample line inlet heights. Subjective injury evaluation - (1.52 cm rain)
	19	0.08 cm rain
	21	Adjusted sample line inlet heights - (0.66 cm rain)
	22	Rain - no dispensing - (1.14 cm rain)
	24	0.08 cm rain
	25	Adjusted sample line inlet heights
	27	Wheat heading - both cultivars - (0.15 cm rain)
	28	Rain - no dispensing - (1.17 cm rain)
	29	Rain - no PM dispensing. Lodging in 2 plots, CF (severe) and NF + 0.06 (moderate), in one block (rep C) - (0.53 cm rain)
	30	Rain - no AM dispensing. Lodging in 1 more rep C plot, NF (moderate) - (0.86 cm rain)
	31	Lodging in 1 more rep C plot, NF + 0.02 (light)
June	2	Rain - no dispensing - (0.25 cm rain)
	3	0.13 cm rain
	4	Adjusted sample line inlet height. Lodging still severe in rep C CF and NF + 0.06 and moderate in rep C NF
	5	0.18 cm rain
	9	Rain - no AM dispensing. Flowering initiating - (0.33 cm rain)

Table 4.1.2.1. Continued.

Month	Day	Event
June	13	Changed particle filters on fans
	14	0.66 cm rain
	19	Random sample line calibration checks
	24	Foliar injury evaluations
	26	0.02 cm rain
	27	4.45 cm rain
	28	0.13 cm rain
	29	0.89 cm rain
	30	Last day of O_3 dispensing - (0.76 cm rain)
July	1	11.40 cm rain
	3	0.53 cm rain
	5-9	Harvested wheat heads and stems
	11	Independent instrument audit
	18	Soil samples collected from all plots

The subplot treatments were the two wheat cultivars, 'Abe' and 'Arthur-71.' The open-top chambers were established over the plots on 6 May, and the fans operated from 0500-2130 CST. Ozone additions were initiated on 8 May when the plants were in the 3-4 leaf stage. Ozone additions were terminated on 30 June when the plants in all treatments had brown leaves, stems, and heads. Stand densities were 137-196 heads/m.

Methods for ozone dispensing and monitoring were as described in the 1982 NCLAN annual report (Heck et al., 1983a). Each plot was sampled for 2 out of every 16 minutes. Sample line losses were 5%. Ozone was not dispensed on three full and five half days due to rain.

Ambient SO_2 was monitored with a TECO Model 43 Pulsed Fluorescent SO_2 analyzer during June. Calibration was accomplished with a CSI 1700 Gas Phase Titration Calibrator and bottled SO_2.

Foliar injury was estimated for all treatments in one replication on 24 June. Four randomly selected flag leaves/cultivar in each plot were evaluated for percent chlorosis, stipple, and necrosis.

The middle two 2-meter row sections of each cultivar were harvested from each plot on 5-9 July. Numbers of heads/m and plant height were recorded and grain was hand-threshed and cleaned, oven dried to <1% moisture content (to assure that sample differences were not confounded by differing moisture content) and weighed according to the NCLAN Biological QA plan. The stems were also dried and weighed.

Seed weight/m row (yield) was adjusted to reflect 14% moisture content and converted to kg/ha. The weight of 100 seeds (100-seed wt) was also obtained for each plot. The number of seeds/m was calculated by dividing the seed weight/m by the 100-seed wt and multiplying by 100. Soil samples collected after harvest were sent to the Soil and Plant Analysis Laboratory, University of Wisconsin, for analysis of pH, organic matter, P, and K.

Twenty-nine "companion" plots were established between the treatment plots to be used to measure yield variability across the field for possible covariance analysis. However, lodging and birds caused considerable damage in the companion plots and then could not be used in covariance analysis.

Grain yield, 100-seed weight, seed weight per head, number of seeds per head, number of seeds per meter row, number of heads per meter row, stem weight per meter row, and plant height were analyzed by a split-split-plot analysis of variance. Analysis of covariance (by cultivar) was also performed for grain yield, number of seeds/m, and stem weight/m using number of heads as the covariate. Weibull regression models were developed for each cultivar, the combined cultivars, and the combined 1982 and 1983 data sets.

4.1.2.3. Results and discussion

Pollutant concentrations. The mean seasonal O_3 concentrations (7-h/day mean) from 8 May to 30 June 1983 for the AA, CF, NF, NF + 0.02, NF + 0.04, and NF + 0.06 treatments were 0.045 ppm, 0.018 ppm, 0.044 ppm, 0.062 ppm, 0.078 ppm, and 0.095 ppm, respectively (Table 4.1.2.2). The

Table 4.1.2.2. Highest and second highest hourly (within the 0900-1600 CST timeframe) and 7-h O^3 mean and the seasonal 7-h (0900-1600 CST) mean for each treatment, 8 May - 30 June at Argonne, IL.

Treatment	7-h/day Values (ppm)			1-h/day Peak Values (ppm)		
	Seasonal Mean*	Highest**	Second Highest	Seasonal Mean*	Highest**	Second Highest
AA	0.045	0.098	0.092	0.053	0.116 (0.135)	0.114
CF	0.018	0.060	0.043	0.025	0.071 (0.097)	0.066
NF	0.044	0.099	0.097	0.053	0.121 (0.130)	0.119
NF + 0.02	0.062	0.122	0.119	0.075	0.145	0.144
NF + 0.04	0.078	0.141	0.141	0.094	0.166	0.165
NF + 0.06	0.095	0.157	0.156	0.116	0.186	0.180

*Each seasonal mean value is derived from the average of 10-12 2-minute samples per hour.

**Highest hourly value occurred outside the 0900-1600 CST timeframe.

seasonal mean of the daily 1-h peaks was about 20% higher in each treatment except the CF, which was about 40% higher. Seven-h/day mean and 1-h/day highest and second highest values have also been provided. The CF chambers were effective in excluding an average of 60% of the ambient O_3. The NAAQS for O_3 was not violated in the AA, CF, or NF treatments.

The daily 7-h and 24-h mean ambient O_3 concentrations between 1 May and 15 July 1983 are shown in Figure 4.1.2.1. The highest 7-h mean was 0.098 ppm on 25 June and the highest 24-h mean was 0.064 ppm on 13 June. The mean seasonal hourly average diurnal fluctuations in O_3 concentrations for all treatments are shown in Figure 4.1.2.2.

SO_2 was detected during 30% of the hours in June 1983. The highest 24-h mean, 3-h mean, 1-h mean, and instantaneous values were 0.018 ppm, 0.063 ppm, 0.120 ppm, and 0.180 ppm, respectively. The monthly mean values were 0.005 ppm (24-h), 0.020 ppm (3-h peak), and 0.033 ppm (1-h peak). The elevated SO_2 concentrations occurred mostly outside of the 0900-1600 CST O_3 addition period - 60% of the 1-h peak values occurred between 2100 and 0300. On six days the 3-h peak values occurred at least partly during the 7-h O_3 addition period.

Foliar injury. Injury occurred on both cultivars in all O_3 treatments above ambient (Table 4.1.2.3). While both cultivars exhibited a similar total amount of injury in all treatments, 'Arthur-71' exhibited considerably more necrotic tissue than 'Abe' at the two highest O_3 treatments.

Yield. The spring of 1983 was excessively wet (18.6 cm rain in May) and the wheat plants grew 10-15 cm taller than normal. Three of the plots in one block (CF, NF, NF + 0.06) had to be discarded because of severe lodging which occurred just after heading.

Split-plot analysis of variance indicated significant (P = 0.05) O_3 and cultivar effects for grain yield, 100-seed weight, and number of heads per meter row. Significant O_3 effects were also noted for number of seeds per meter row and significant cultivar effects were also found for number of seeds per head. There were no significant O_3 x rep or O_3 x cultivar effects. Since the number of heads per meter row had already been determined prior to initiation of the O_3 treatments, the significant difference among treatments was not, in fact, due to O_3. Thus, the grain yield, number of seeds per meter row, and stem weight per meter row values were adjusted by analysis of covariance using number of heads as the covariate. That analysis indicated significant O_3 and cultivar effects for grain yield, and significant O_3 effects for number of seeds per meter row. The yield data are presented in Table 4.1.2.4. There were increases in seed number for both cultivars as O_3 increased to 0.078 ppm which appeared to counteract the O_3 effect on 100-seed weight and reduce the significance of the grain yield reductions. The grain yield reductions were a result of individual seed weight (100-seed weight) reductions. (In 1982, reductions in seed number had accounted for about one-third of the overall yield reduction in the range of 15%). Grain weight was affected more than stem weight by the O_3 treatments. Such a response could reflect the previous damage to the photosynthetic capacity needed to fill the heads or the higher O_3 concentrations during head filling (7-h mean O_3 of 0.039 ppm for May and 0.057 ppm for June).

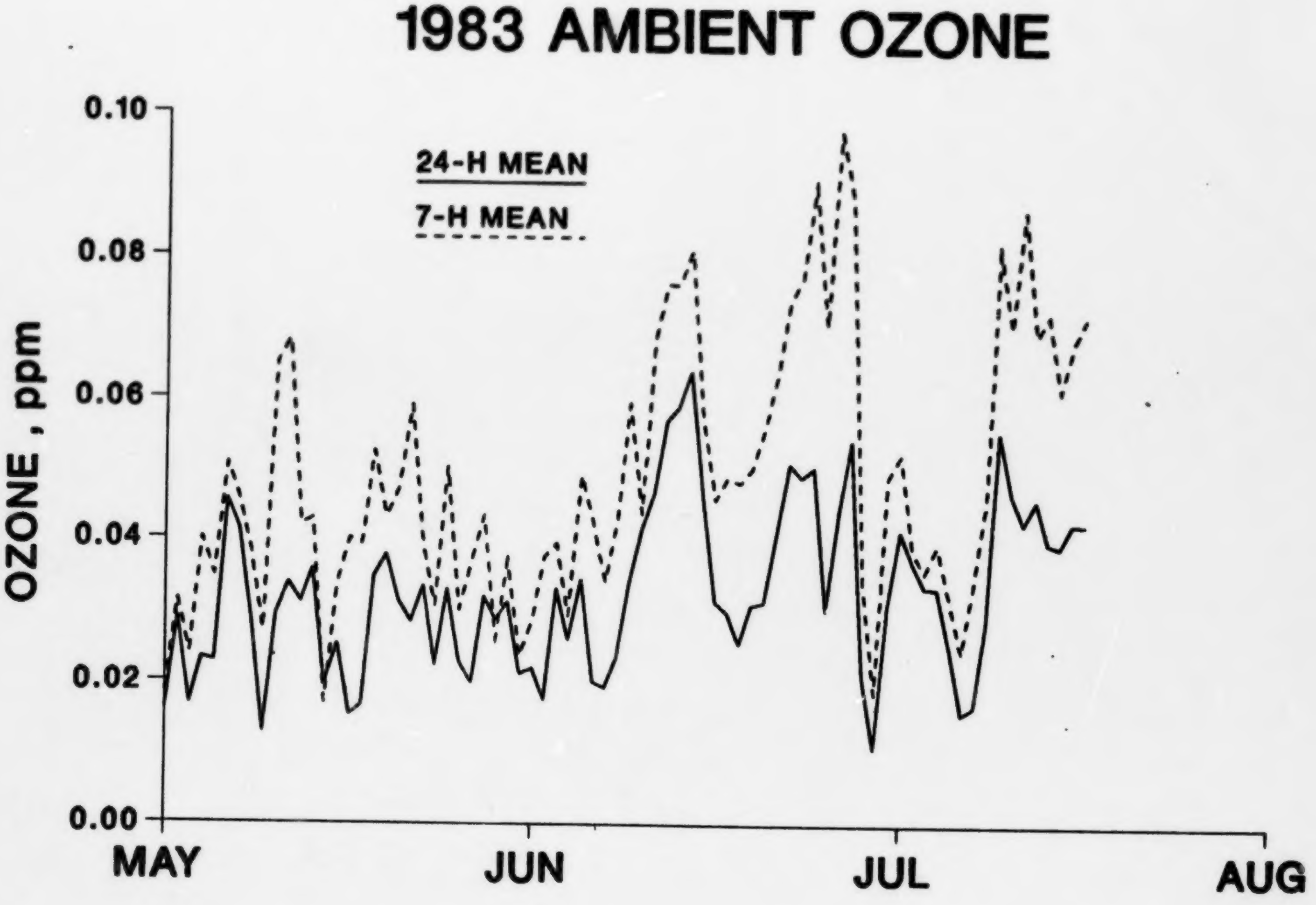

Figure 4.1.2.1. Daily 7-h (0900-1600 CST) and 24-h O_3 concentrations from 1 May - 15 July 1983, at Argonne, IL, measured at a 3-meter height. Experimental treatments on wheat were from 8 May - 30 June.

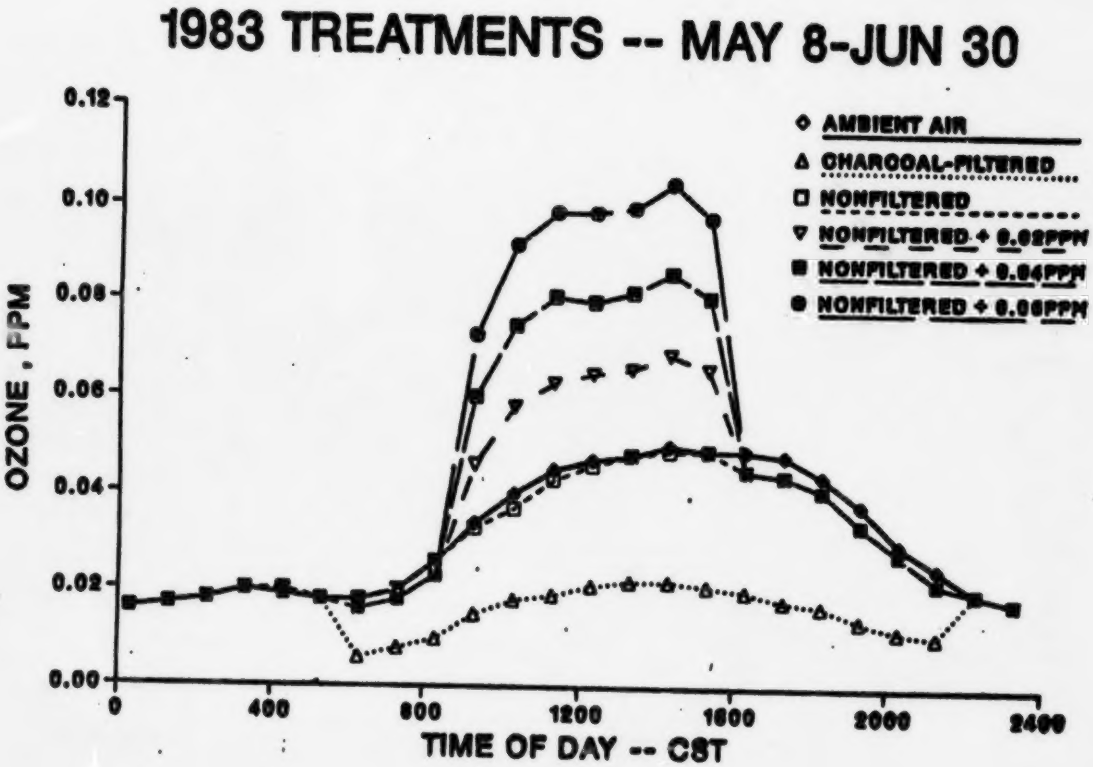

Figure 4.1.2.2. Mean seasonal hourly average diurnal fluctuations in O_3 concentrations for all treatments from 8 May - 30 June 1983.

Table 4.1.2.3. Mean percent foliar injury on four randomly selected flag leaves of winter wheat plants of each cultivar in each treatment exposed for 53 days at Argonne, IL, in 1983.*

	A			A 71		
Treatment	Chlorosis and Stipple	Necrosis	Total	Chlorosis and Stipple	Necrosis	Total
			%			
AA	8	5	13	10	5	15
CF	8	1	9	11	4	15
NF	6	5	11	13	5	18
+ 0.02	15	4	19	34	5	39
+ 0.04	51	5	56	38	30	68
+ 0.06	80	6	86	58	26	84

*Evaluated one of three replicates

Table 4.1.2.4. Yield responses of two cultivars of winter wheat exposed to charcoal filtered air (CF), ambient air open plot (AA), and ambient air plus O_3 in open-top chambers (NF) for 7-h/day for 53 days during 1983.

		Abe					Arthur-71				
Treatment	O_3 Conc. (ppm)	# heads/m	# seeds/m*	kg/ha*	100-seed weight (g)	stem weight/m (g)*	# heads/m	# seeds/m*	kg/ha*	100-seed weight (g)	Stem weight/m (g)*
AA	0.045	143	3037	6381	3.68	130	161	3429	6695	3.47	130
CF	0.018	167	3080	5808	3.44	124	160	2995	5151	3.10	115
NF	0.044	196	3295	5986	3.45	126	143	3271	5622	3.13	124
NF+0.02	0.062	154	3163	5982	3.36	117	137	3125	5214	3.04	113
NF+0.04	0.078	160	3175	5762	3.26	119	157	3252	4963	2.73	107
NF+0.06	0.095	155	3042	4939	2.88	112	137	3098	4397	2.59	109
		% of CF					% of CF				
AA	0.045	86	99	110	107	105	100	114	130	112	113
NF	0.044	117	107	103	100	102	89	109	109	101	108
NF+0.02	0.062	92	103	103	98	94	86	104	101	98	98
NF+0.04	0.078	96	103	99	95	96	98	109	96	88	93
NF+0.06	0.095	93	99	85	84	90	86	103	85	84	93

*# seeds/m, kg/ha, and stem weight/m are adjusted values from covariance analysis using # heads as the covariate.

Weibull regression models were fit to the data (Table 4.1.2.5) and the results plotted (Fig. 4.1.2.3). Yield responses of 'Abe' and 'Arthur-71' were nearly identical to each other both in 1982 and 1983 and were combined for each year. The combined cultivar responses between the two years were just significantly different ($P = 0.05$), but there was not much O_3 response in 1983 so the precision on the parameter estimates was not very good (standard errors are large), and thus a combined curve for both cultivars over both years ($R^2 = .87$) was also produced. The response of 'Abe' and 'Arthur-71' was less than that of 'Roland' especially at the lower O_3 concentrations.

Conclusion. Ozone sensitivity was somewhat less in 1983 than in 1982. The soil moisture levels were much greater in 1983, especially in May. While this might suggest that the crop should have been more sensitive to O_3 in 1983, the data of Heggestad (Heck et al., 1983a) suggest that moisture stress may potentiate O_3 effects at near ambient concentations. Our 1982 wheat may have been under moderate moisture stress and thus was more sensitive to moderate O_3 stress. Alternatively, although the seasonal mean O_3 concentrations were similar, the mean O_3 in May 1982 was about 10% higher than in June, while in 1983 the O_3 was about 30% lower in May than in June. This could have led to effects occurring earlier in the season in 1982 (prior to and during anthesis). That idea was supported by the fact that seed numbers and individual seed weight were reduced in 1982, but only individual seed weight was reduced in 1983. Also stem weight was not affected as much as was grain weight in 1983. Winter wheat ('Abe' and 'Arthur-71') is still to be considered as more sensitive than grain sorghum or field corn and less sensitive than soybean (Fig. 4.1.2.4). The cultivar 'Roland', however, is more sensitive than Corsoy soybean (Kress and Miller, 1981; Kress et al., 1983a, 1983b; Kress and Miller, 1983).

4.1.3. Impact of O_3 on Yield of Four Soybean Cultivars (CSRCLAP)--

Lance W. Kress, H. J. Smith, and Joseph E. Miller

4.1.3.1. Introduction

Soybeans are a major crop worldwide, and one of the leading cash crops in the Midwestern U.S. They are sensitive to O_3 and reductions in yield have been demonstrated under ambient field conditions (Kress and Miller, 1983; Heck et al., 1983b).

Research performed within NCLAN has developed exposure-response relationships for six soybean cultivars, and statistical comparisons have suggested that the yield responses to O_3 may be homogeneous (Heck et al., 1984b). However, significant year-to-year variation and exposure dynamics variation has been shown for one cultivar (Davis) at the southeast NCLAN site. Percent yield reductions have been predicted to be 12.1% at 0.05 ppm O_3 (seasonal 7-h/day mean--approximate ambient at Agronne), 17% at 0.06 ppm, and 30.7% at 0.09 ppm (Heck et al., 1984b).

Only one cultivar of soybean (Corsoy-79) has been examined at the Midwestern NCLAN site (Argonne). Since soybeans are especially important in the Midwest, four cultivars were tested in 1983. Of the public varieties, 'Williams-79,' was the most commonly planted cultivar in Illinois (9%). 'Pella' was a relatively new cultivar rapidly gaining

Table 4.1.2.5. Parameters for the fitted Weibull equations for overall grain yield of three winter wheat cultivars exposed to O_3 (7-h/day, 7 days/week) for 55 days in 1982 and of two winter wheat cultivars exposed to O_3 for 53 days in 1983 in Argonne, IL.

Parameter*	Roland 1982	Abe + Arthur-71 1982	Abe + Arthur-71 1983	Abe + Arthur-71 1982 + 1983
α	5426 (325)	4877 (275)**	5641 (223)**	5295 (226)†
σ	0.113 (0.005)	0.150 (0.010)	0.123 (0.028)	0.145 (0.008)
c	1.734 (0.330)	2.378 (0.612)	7.060 (6.137)	3.326 (0.655)

*α = grain yield at 0.00 ppm of O_3.
σ = concentration in ppm at which yield is 0.37 alpha.
c = dimensionless shape parameters.

Values in parenthesis are one standard error.

**Mean of the two alpha values generated for each cultivar by a common response Weibull model.

†Mean of the four alpha values generated by a common response Weibull model.

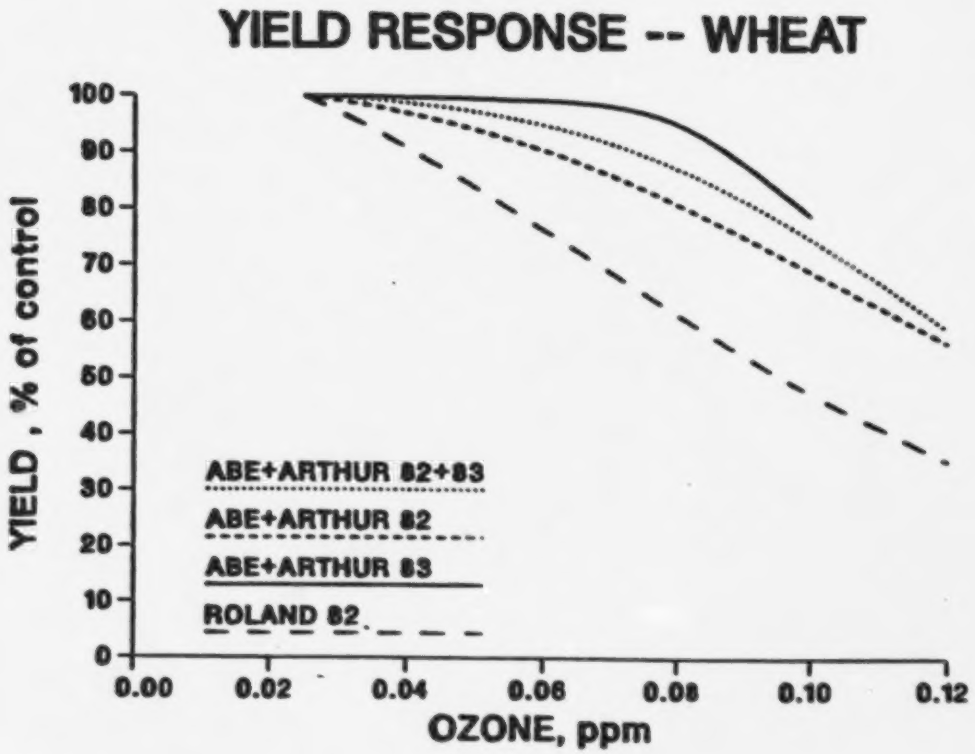

Figure 4.1.2.3. Relative winter wheat grain yield (kg/ha) performance curves from fitted Weibull models for three cultivars indicating grain yield as a function of 7-h/day seasonal mean O_3 concentration, using a reference concentration of 0.025 ppm. The responses of 'Abe' and 'Arthur-71' were not significantly different (P = 0.01) from each other in either 1982 or 1983.

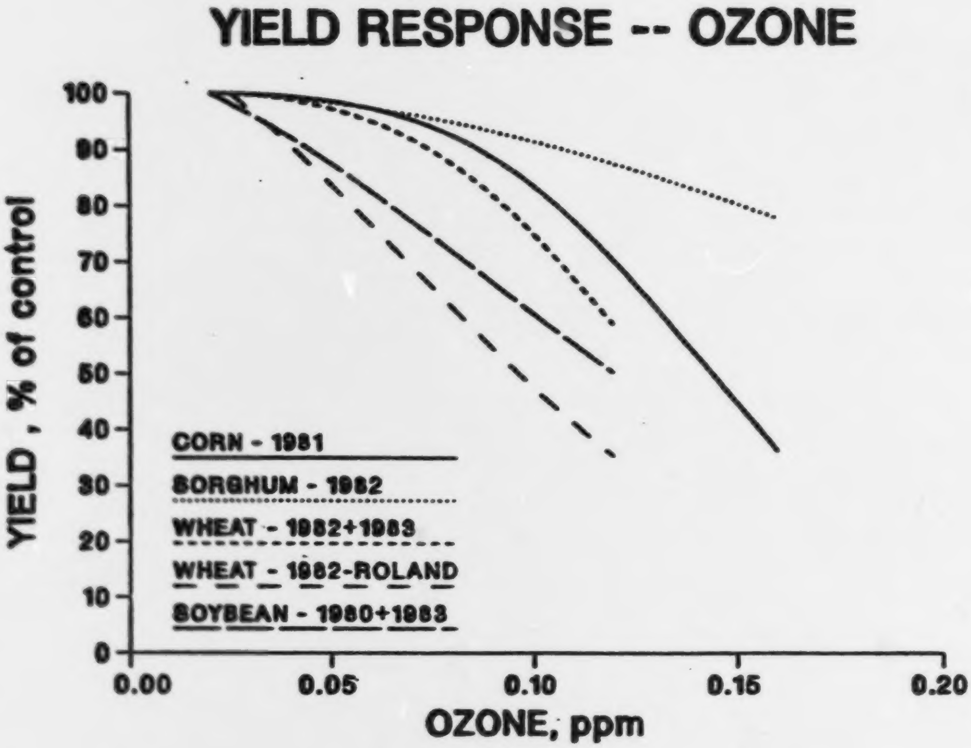

Figure 4.1.2.4. Relative seed yield (kg/ha) performance curves from fitted Weibull models for grain sorghum, field corn, winter wheat, and soybean indicating seed yield as a function of 7-h/day seasonal mean O_3 concentration, using a reference concentration of 0.025 ppm.

popularity (3%). 'Corsoy-79' ranked seventh in the state (2%), but first in the northeastern Illinois counties (9%). 'Amsoy-71' ranked tenth (1%) in Illinois, and has been noted as sensitive to acid precipitation effects. The objective of this study was to determine the effects of daily O_3 exposures on the yield of these four soybean cultivars.

4.1.3.2. Materials and methods

Many of the important events concerning the experiment have been listed in Table 4.1.3.1. Seed of four cultivars of soybean (*Glycine max* (L.) Merr., 'Amsoy-71,' 'Corsoy-79,' 'Pella,' 'Williams-79') were sown; two seeds every 3.8 cm in 2-m rows 76 cm apart on 12 and 13 July 1983. (*Note*: This was 5 to 6 weeks late for soybean in northern Illinois; the original planned crop of field corn failed due to dry weather and birds, and this necessitated a late substitution of soybeans; several local farmers also put in a late soybean crop after their corn crops were lost). The cultivars were paired by maturation rate ('Corsoy-79' and 'Amsoy-71,' 'Pella' and 'Williams-79') in adjacent plots of similar treatments. A border row of soybeans was planted 76 cm on either side of the experimental rows using pooled seed of the two cultivars in that plot for competition. There were three replications of five O_3 treatments. Each soybean pair occurred in each treatment and each block. In reps 1 and 3 'Corsoy-79' and 'Williams-79' were in the east row of their respective plots, and in rep 2 'Amsoy-71' and 'Pella' were in the east row of their respective plots.

The soil is a Morley silt loam (fine, illitic, mesic Typic Hapludalf), upland timber soil. This soil has a high water-holding capacity and low permeability. In reps 1 and 2 it has a pH of 6.8 ± .5 and 60,000 ± 9,000 kg/ha organic matter. In rep 3 it has a pH of 6.2 ± .3 and 38,000 ± 2,000 kg/ha organic matter. The area of reps 1 and 2 had been fertilized in preparation for corn while rep 3 had been fertilized in preparation for soybean (Table 4.1.3.1.). Due to a prolonged dry spell in late July and early August, all plots were watered twice in August by hand at the rate of 7 liters per meter row (2.54 cm irrigation). The night following the second watering (16 August) we had 3.8 cm of rainfall. In general the weather was hotter and drier than normal in July and August, and wetter than normal in September. The first frost occurred on 27 October. Total rainfall from July through 18 October was 35.6 cm (about normal).

The experimental design was a split-split-plot design with the whole plot treatments arranged in a randomized complete block design with three replications. The whole plot treatments were the five O_3 treatments:

AA, no chamber (ambient air);

CF, charcoal-filtered air chamber;

NF, nonfiltered air chambers with a small amount of O_3 added to provide a concentration approximating that in the AA plot; and

NF + 0.03 and NF + 0.06, nonfiltered air with O_3 added to 0.03 and 0.06 ppm above ambient, respectively.

Table 4.1.3.1. Dates of important events during the 1983 studies to determine the effect of O_3 on yield of four soybean cultivars at Argonne, IL.

Month	Day	Event
June	14	Fertilized rep A & B plots in preparation for planting field corn - 229 kg/ha N, 163 kg/ha P, 163 kg/ha K (corn crop failed and these plots were then used for soybean).
	23	Fertilized rep C plots - 41 kg/ha N, 163 kg/ha P, 163 kg/ha K
	27	4.45 cm rainfall
	28	0.13 cm rainfall
	29	0.89 cm rainfall
	30	0.76 cm rainfall
July	1	11.40 cm rainfall
	3	0.53 cm rainfall
	11	Independent instrument audit
	12	Planted rep A and B
	13	Planted rep C
	17	Calibrated O_3 sample lines @ 0.2 ppm O_3
	18	0.23 cm rainfall
	19	1.27 cm rainfall
	21	Soybeans emerging. Random sample line cal. checks (0.58 cm rainfall)
	26-27	Panels and fans on
	27	Thin to one plant every 3.8 cm
	28	Began O_3 dispensing. Plants in early first trifoliolate stage - 10-15 cm tall
	29	0.13 cm rainfall
	30	0.10 cm rainfall
August	2	Random sample line calibration checks
	8	Watered all plots - 7 liters per meter row (2.54 cm irrigation)
	10	0.76 cm rainfall
	14	Random sample line calibration checks
	16	Watered all plots - 7 liters per meter row (2.54 cm irrigation, 3.81 cm rainfall)
	16	Flowering initiated - 'Corsoy,' 'Amsoy,' 'Pella'
	18	Flowering initiated - 'Williams'
	19	Adjusted sample line inlet height
	25	Rain - no PM dispensing (0.56 cm rainfall)
	26	Rain - no PM dispensing (0.61 cm rainfall)
	27	0.08 cm rainfall
September	1	Adjust sample line inlet height
	3	Random sample line calibration checks
	5	2.44 cm rainfall
	6	Rain - no AM dispensing (0.13 cm rainfall)
	7	Check all sampling solenoids and random sample line calibration checks
	10	0.53 cm rainfall

Table 4.1.3.1 (continued).

Month	Day	Event
September	12	Replaced particle filters on fans
	15	Rain - no PM dispensing (1.07 cm rainfall)
	16	0.05 cm rainfall
	17	1.83 cm rainfall
	18	3.56 cm rainfall
	19	Rain - no AM dispensing (0.46 cm rainfall)
	20	Rain - no dispensing (1.68 cm rainfall)
	22	Fans allowed to run all night to prevent potential frost damage - no frost occurred on any plots, including AA
	25	Rain - no dispensing (0.05 cm rainfall)
October	8	Rain - no AM dispensing (0.51 cm rainfall)
	11	Foliar injury evaluations (1.75 cm rainfall)
	12	Rain - no AM dispensing (0.51 cm rainfall)
	13	0.23 cm rainfall
	18	Last day of O_3 dispensing
	19	Foliar injury evaluations (0.08 cm rainfall)
	20	1.52 cm rainfall
	23	4.72 cm rainfall
	24	0.05 cm rainfall
	27-31	Sample line calibration checks @ 0.20 ppm O_3
	19-31	Harvested soybean pods as leaves abscised and pods turned brown
November	1-11	Harvested soybean pods as leaves abscised and pods turned brown
	1-13	Removed panels from chambers
	29	Soil samples collected from each plot

The subplot treatments were the two groups of two cultivars each. The sub-subplot treatments were the two cultivars within each of the cultivar groups. The open-top chambers were established over the plots on 26-27 July, and the fans operated from 0500-2130 CST. Ozone additions were initiated on 28 July with the plants in the early first trifoliolate stage. Ozone additions were terminated on 18 October when the leaves in all plots were chlorotic, necrotic, or had abscised.

Methods for O_3 dispensing and monitoring were as described in the 1982 NCLAN annual report (Heck et al. 1983a). Each plot was sampled for 2 minutes out of every 22 minutes. Sample line O_3 losses varied from 1-9%, and the O_3 values from each plot were adjusted individually. Ozone was not dispensed on two full and seven half days due to rain.

Ambient SO_2 was monitored continuously during the experiment with a TECO Model 43 Pulsed Fluorescent SO_2 analyzer. Calibration was accomplished with a CSI 1700 Gas Phase Titration Calibrator and bottled SO_2.

Foliar injury was estimated on 11 October in all plots. Four randomly selected plants per cultivar were evaluated for percent stippling on the lower leaves (below leaf number five) and for percent chlorosis (senescence) on the top five leaves. On 19 October all plots were evaluated for overall percent of green foliage remaining in the canopy. Harvest date for each plot, between 19 October and 11 November, was determined by the time at which the leaves abscised and the pods turned brown. Pods from two 1-meter row sections of each cultivar were harvested from each plot. Seeds were separated by hand, counted, oven dried to <1% moisture content (to assure that sample differences were not confounded by differing moisture content), and weighed. Measurements taken at harvest were number of plants/m, number of pods with at least one seed, number of seedless pods, and plant height. Seed weight/m row was adjusted to reflect 14% moisture content and converted to kg/ha. The weight of 100 seeds (100 swt) was calculated by dividing seed weight/m by the number of seeds and multiplying by 100. Soil samples collected after harvest were sent to the Soil and Plant Analysis Laboratory, University of Wisconsin, for analysis of pH, organic matter, P, and K.

The yield data were analyzed by a split-split-plot analysis of variance. The sources of variation were block, treatment, block x treatment (Error a), group (the two sets of cultivar pairs), treatment x group, block x treatment within group (Error b), cultivar within group, treatment x cultivar within group, and residual (Error c). Weibull regression models were developed for each cultivar, the combined cultivars, the combined 1980 and 1983 'Corsoy-79' cultivars, and the combined 1980 and 1983 data (five data sets/four cultivars).

4.1.3.3. Results and discussion

Pollutant concentrations. The mean seasonal O_3 concentrations (7-h/day mean) from 28 July to 18 October for the AA, CF, NF, NF + 0.03, and NF + 0.06 treatments were 0.046 ppm, 0.022 ppm, 0.046 ppm, 0.071 ppm, and 0.094 ppm, respectively (Table 4.1.3.2). The seasonal mean of the daily 1-h peaks was about 25% higher in each treatment except the CF, which was about 40% higher. Seven-h/day and 1-h/day high and second high values have also been provided. The CF chambers were effective in excluding an

Table 4.1.3.2. Highest and second highest hourly (between 0900-1600 CST) and the 7-h mean O_3 values, the seasonal 1-h daily peak mean, and the seasonal 7-h (0900-1600 CST) mean for each treatment, 28 July - 18 October 1983, at Argonne, IL

	7-h/day Values (ppm)			1-h/day Peak Values (ppm)		
Treatment	Seasonal Mean*	Highest	2nd Highest	Seasonal Mean*	Highest	2nd Highest
AA	0.046	0.092	0.090	0.060	0.147	0.139
CF	0.022	0.055	0.052	0.031	0.072	0.065
NF	0.046	0.090	0.083	0.058	0.139	0.124
NF + 0.03	0.071	0.118	0.113	0.090	0.173	0.160
NF + 0.06	0.094	0.152	0.144	0.118	0.216	0.210

*Each seasonal mean value is derived from the average of 7 to 9 2-minute samples per hour.

average of 50% of the ambient O_3. The NAAQS of 0.12 ppm for 1 h was violated in all treatments except the CF.

The daily 7-h and 24-h mean ambient O_3 concentrations between 16 July and 31 October 1983 are shown in Figure 4.1.3.1. The highest 7-h mean was 0.104 ppm on 18 August and the highest 24-h mean was 0.067 ppm on 28 July. The mean seasonal hourly average diurnal fluctuations in O_3 concentrations for all treatments are shown in Figure 4.1.3.2.

Sulfur dioxide was detected (detection limit = 0.005 ppm) during 33% of the hours between 28 July and 18 October, 1983. The highest 24-h mean, 3-hr mean, 1-hr mean, and instantaneous peak values were 0.020 ppm, 0.110 ppm, 0.145 ppm, and 0.185 ppm, respectively. The seasonal mean SO_2 values were 0.005 ppm [24-h, 0.021 ppm (3-hr peak)], and 0.030 ppm (1-h peak). Sixty-two percent of the 1-h peak values occurred during the 7-h O_3 addition period and 68% of the 3-h peak means occurred at least partly during the 7-h O_3 addition period.

Foliar injury. There was considerable injury noted on 11 October for all four soybean cultivars at the two elevated O_3 treatments (Table 4.1.3.3). There was little difference among the cultivars in terms of typical oxidant-induced purple stipple. The percentage of chlorotic leaves (indicative of senescence) was similar for 'Amsoy-71' and 'Corsoy-79,' but considerably less for 'Williams-79' and 'Pella.' The treatment differences in chlorotic leaves for "Williams-79' were similar, however, to those for 'Amsoy-71' and 'Corsoy-79.' All cultivars exhibited generally increased stipple and chlorosis as the O_3 concentrations increased. There were no obvious effects of O_3 treatments on plant height.

Yield. The analysis of variance of the chambered plot data indicated significant treatment and group (cultivar pairs) effects for kg/ha yield, but only significant group and cultivar within group effects for individual seed weight (100 swt). An analysis of variance for each cultivar separately [without the replication effect in the model and using the pooled error mean squares (EMS)] indicated significant ($P = 0.05$) O_3 effects for 'Corsoy-79,' Pella, and 'Williams-79,' but not for 'Amsoy-71' (Prob. > F = 0.118). The percentage yield reductions as O_3 concentrations increased were rather similar for all four cultivars, although 'Amsoy-71' appeared to be less affected than the other three by ambient O_3 (Table 4.1.3.4). At the highest O_3 concentration, reductions in individual seed weight accounted for about half of the overall yield reduction (kg/ha), as has been noted in other studies (Kress and Miller, 1983; Kress et al., this report).

The late planting caused senescence to occur later in the fall (mid-October), but overall seed yield was probably reduced. (The yields of these four cultivars in the University of Illinois soybean variety trials in northern Illinois were: 'Amsoy-71' -- 2600 kg/ha; 'Corsoy-79' -- 2868 kg/ha; 'Pella' -- 3202 kg/ha; and 'Williams-82' -- 3002 kg/ha ['Williams-79' was not used]). However, relative response to the O_3 stress may not have been affected.

Weibull regression models for each cultivar and for the combined cultivars were fitted to the data (Tables 4.1.3.5 and 4.1.3.6; Fig. 4.1.3.3). The regression for each cultivar was significant at $P = 0.05$.

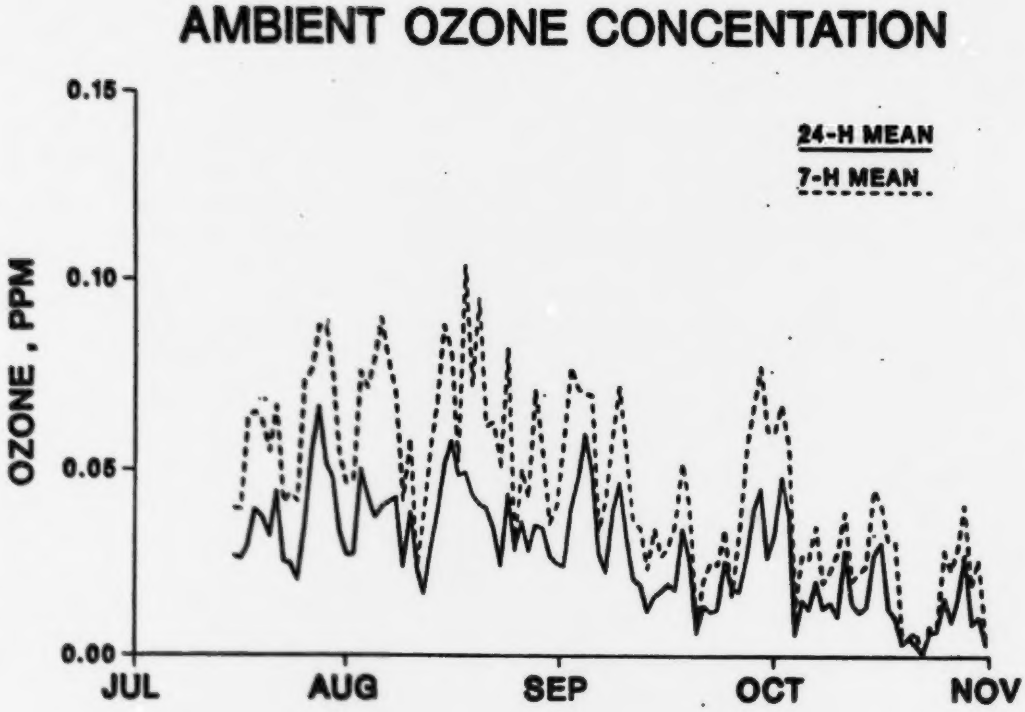

Figure 4.1.3.1. Daily 7-h (0900-1600 CST) and 24-h O_3 concentrations from 16 July - 31 October 1983, at Argonne, IL, measured at a 3-meter height. Experimental treatments on soybeans were from 28 July - 18 October.

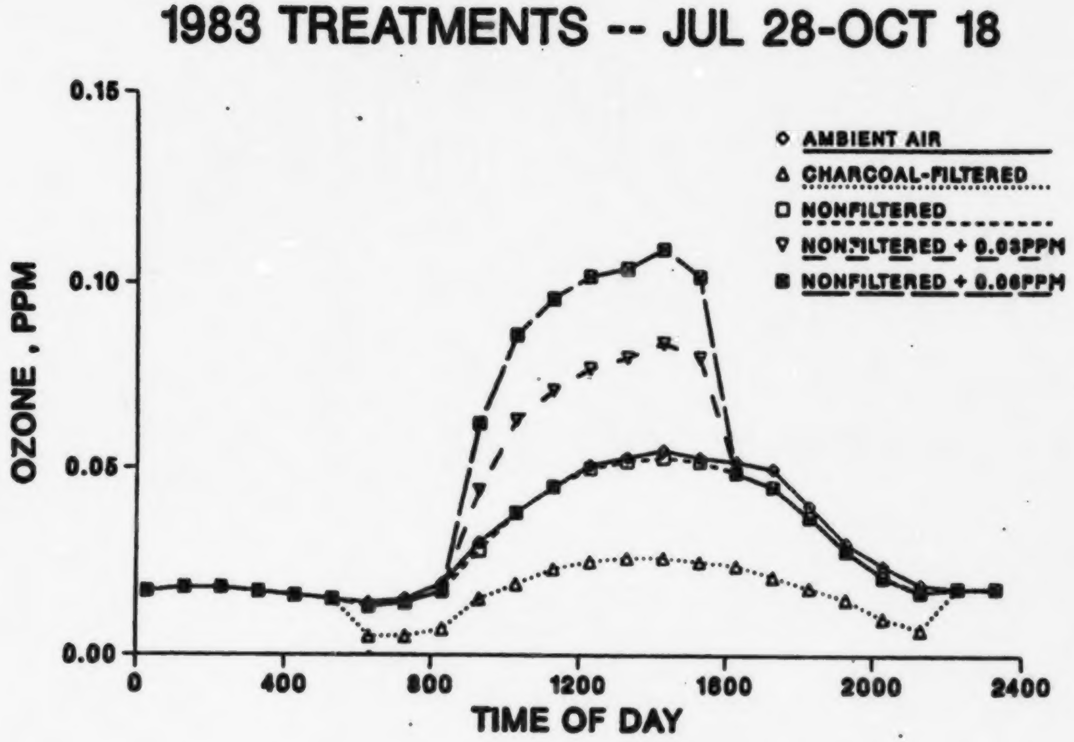

Figure 4.1.3.2. Mean seasonal hourly average diurnal fluctuations in O_3 concentrations for all treatments from 28 July - 18 October 1983.

Table 4.1.3.3. Plant height and mean percent foliar injury (evaluated on 11 October) on four randomly selected plants of each soybean cultivar in each treatment exposed to O_3 for 75 days at Argonne, IL, in 1983

	Amsoy-71			Corsoy-79		
Treatments	Ht (cm)	Stipple*	Chlorosis**	Ht (cm)	Stipple*	Chlorosis**
		%			%	
AA	46	2	35	44	4	53
CF	52	1	42	46	1	67
NF	51	5	50	41	5	68
+ 0.03	53	27	70	49	27	99
+ 0.06	41	63	95	38	53	99
	Pella			Williams-79		
AA	56	1	4	50	1	4
CF	72	1	1	66	1	2
NF	58	2	9	52	2	7
+ 0.03	67	37	12	52	27	36
+ 0.06	60	47	10	54	53	40

*Stipple evaluated on all lower leaves, below leaf number 5.

**Chlorosis evaluated on the top 5 leaves.

Table 4.1.3.4. Yield response of four soybean cultivars exposed to O_3 in open-top chambers for 83 days (7-hr/day seasonal mean concentrations)

O_3 (ppm)	A 71		C 79		P		W 79	
	Kg/ha	100 swt*	Kg/ha	100 swt*	Kg/ha	100 swt*	Kg/ha	100 swt*
0.022	1978	15.9	2096	15.2	2744	19.7	2536	17.8
0.046	1793	15.1	1671	14.5	2103	18.1	1887	16.7
0.071	1609	13.8	1780	12.4	2300	17.1	1764	14.1
0.094	1231	13.1	1139	11.1	1863	17.0	1735	14.7
0.046 (AA)	1967	14.7	1936	13.9	2109	17.3	2078	15.8
% Reduction								
0.046	9	5	20	5	23	8	26	6
0.071	19	13	15	18	16	13	30	21
0.094	38	18	46	27	32	14	32	17
0.046 (AA)	1	8	8	9	23	12	18	11

*100 swt = weight of 100 seeds.

Table 4.1.3.5. Percent yield reductions predicted from Weibull models generated with various soybean data sets.

Cultivars and Reference	O_3 Concentration (ppm)			
	.04	.05	.06	.09
	%			
'Amsoy-71,' 'Corsoy-79,' 'Pella,' 'Williams-79' (this study)	7.7	12.5	17.1	29.7
'Corsoy-79' (1980 + 1983) this study and Kress and Miller, 1983)	5.3	10.0	15.4	34.7
'Amsoy-71,' 'Corsoy-79' (1980 + 1983), 'Pella,' 'Williams-79' (this study and Kress and Miller, 1983)	6.3	11.1	16.3	32.7
'Corsoy-79' (1980), 'Davis,' 'Essex,' 'Williams,' 'Forrest,' 'Hodgson' (Heck et al., 1984b)	7.3	12.1	17.0	30.7

Table 4.1.3.6. Parameters for the fitted Weibull equations for overall seed yield of four soybean cultivars exposed to O_3 (7-h/day, 7 days/week) for 83 days in 1983 at Argonne, IL.

Parameter*	Amsoy-71	Corsoy-79	Pella	Williams-79	Combined
α	1933 (217)	1907 (167)	3000 (1731)	3000 (3081)	2540 (610)**
σ	0.118 (0.033)	0.106 (0.015)	0.237 (0.270)	0.194 (0.145)	0.183 (0.072)
c	3.448 (3.973)	6.076 (6.594)	0.853 (2.338)	0.678 (2.216)	1.033 (1.168)

* = seed yield at 0.00 ppm of O_3.
= concentration in ppm at which yield is 0.37 alpha.
c = dimensionless shape parameters.

Values in parentheses are one standard error.

**Mean of the four α values generated by a common response Weibull model.

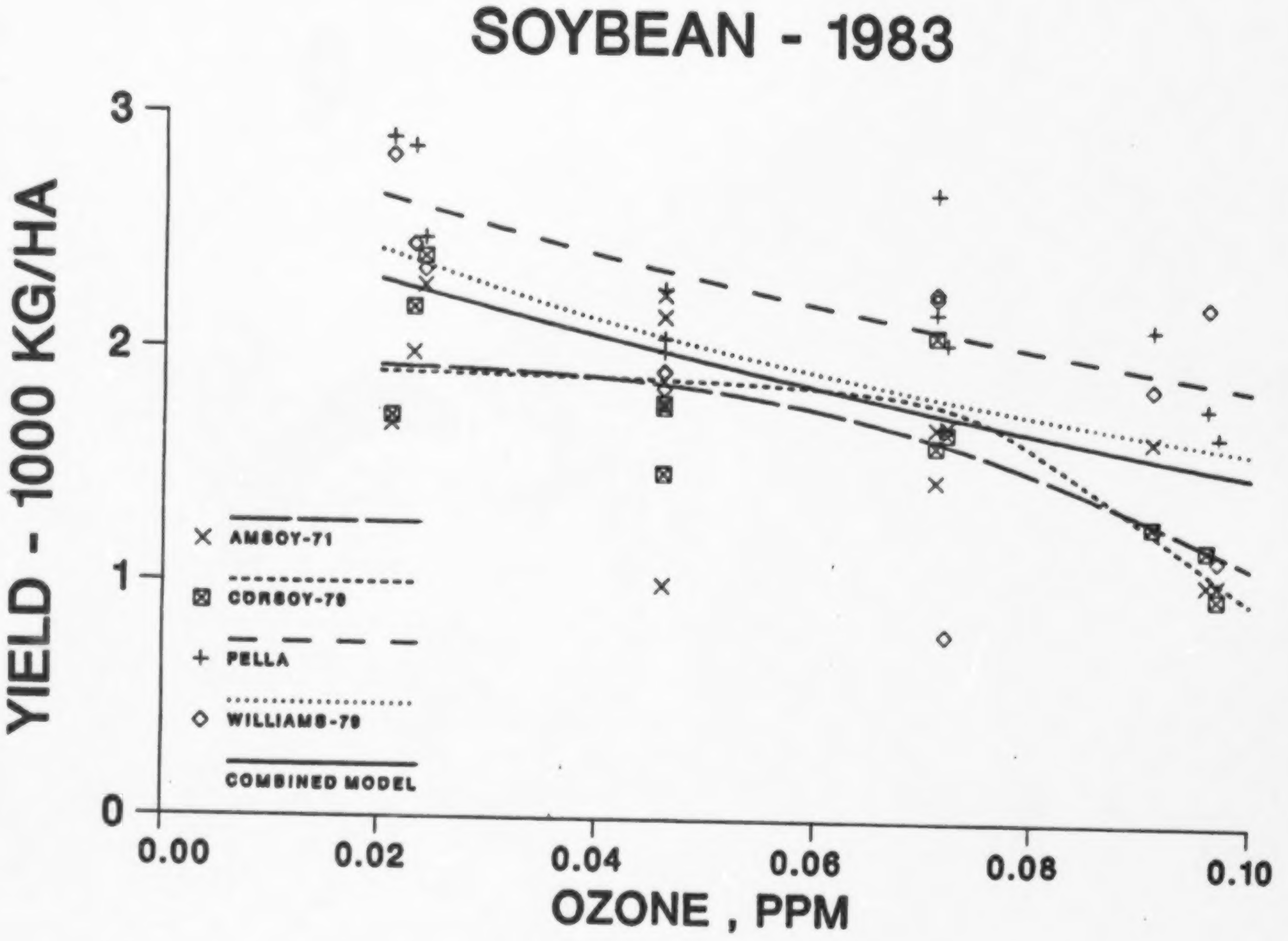

Figure 4.1.3.3. Fitted Weibull model regression curves for four soybean cultivars (and a common model) indicating seed yield as a function of 7-h/day seasonal mean O_3 concentration. Plants were exposed for 83 days in open-top field chambers.

The curves appear different, but there was no O_3 x cultivar interaction and use of the Weibull models for a test for homogeneity indicated that the responses to O_3 of the four cultivars were not heterogeneous and that the common model (with an R^2 of 0.865) could be used to describe the responses of all four cultivars. The predicted yield reductions from the common model were 12.5% at 0.05 ppm O_3, 17.1% at 0.06 ppm, and 29.7% at 0.09 ppm, compared to a control of 0.025 ppm O_3 (Table 4.1.3.5). The responses of the 1980 'Corsoy-79' soybean plants (Kress and Miller, 1983) were not different from the 'Corsoy-79' plants in this study, and in fact could be combined with all four cultivars in this study (Table 4.1.3.5). Also, the combined responses to O_3 of 'Amsoy-71' and 'Corsoy-79' in a separate O_3 x SO_2 interaction experiment were similar to most of the previous soybean responses (Kress *et al.*, this report).

Conclusions. The loss estimates produced by the Weibull model generated using these data are nearly identical to those produced from the model of nine other data sets (six cultivars) -- 12.1% at 0.05 ppm O_3, 17% at 0.06 ppm, and 30.7% at 0.09 ppm (Heck *et al.*, 1984b). These data suggest that the yields of different soybean cultivars exposed to O_3 in different regions and in different years may be responding to the O_3 stress in a similar fashion in terms of proportional yield loss. These data will be included with the other data generated in the NCLAN program to evaluate the effects of O_3 on crop yield. Future research will attempt to quantify the effects of soil moisture stress on soybean sensitivity to O_3.

4.1.4. Effects of Exposure Dynamics on Response of Tobacco to O_3 (SERCLAP)--Allen S. Heagle, W. W. Heck, V. M. Lesser, J. O. Rawlings, R. B. Philbeck, F. W. Mowry, and H. V. Marshall

4.1.4.1. Introduction

Ozone dose-crop yield relationships for most NCLAN studies are based on constant additions of O_3 for 7 h per day to the variable O_3 levels in ambient air. Another, perhaps more realistic, method used in several NCLAN studies, is to add O_3 in amounts proportional to ambient O_3 levels. Another improvement might result by extending the exposure time to include all of the daylight period. There is a need to determine whether variations in exposure dynamics which result from each of these methods affect O_3 dose-crop response relationships.

The objectives of this experiment were to compare dose-response relationships for yield of flue-cured tobacco using constant or proportional O_3 additions for 7 h per day and proportional additions for 12 h per day.

4.1.4.2. Materials and methods

Cultural. Seedlings of flue-cured tobacco, *Nicotiana tabacum* L., cv 'McNair 944' obtained from a commercial plant bed were planted in a 0.4 ha field with a two-row planter in rows spaced 105 cm on 18 May. The soil was Appling (clayey, Kaolinitic, thermic, Typic hapludult) which had been fertilized according to soil test recommendations and treated with recommended insecticides, fungicides, and herbicides (Table 4.1.4.1). On

Table 4.1.4.1. Chronology of events during the 1983 study to determine the response of tobacco to ambient O_3 concentrations supplemented with constant or variable O_3

Month	Day	Event
May	3	Applied .946 liters Parlan; 1.26 liters Ridomil; 1.89 liters Diazinon over a .405 hectare area
	18	Tobacco planted with 6-12-18 (N-P-K) fertilizer (204 kilograms)
	19,20	Transplanted tobacco plants into plots (50 cm apart)
	23	Plots chosen, chamber frames put in place
	24	Fan boxes put in place
	25,26	Monitoring lines and dispensing lines put in place
	27	Remainder of fan boxes put in place, top panels installed, Orthene applied (1.12 kg/ha) for flea beetle control
	30	Bottom panels installed, fans on
June	2	Ozone dispensing began
	3,9	Fertilizer applied (15-0-14, N-P-K), 14/plant
	14	Orthene (1.12 kg/ha) applied for budworm control
	16	Furadan applied for cutworms and wireworm control
	20	Irrometers installed at 20 and 30 cm
	22	Orthene (1.12 kg/ha) applied for budworm control
	27	First harvest of ground suckers (unmarketable leaves)
July	5,11	Harvested marketable leaves and suckers
	12	Orthene applied (1.12 kg/ha) for hornworm control
	13,19	Topped tobacco plants below first lateral branch Offshoot-T (16.6 ml/liter) applied for sucker control
	14	Tobacco plants topped
	15,21, 28	Offshoot-T (16.6 ml/liter) applied for sucker control
	18,25	Harvested marketable leaves
	26	Topped plants, Offshoot-T applied
August	1,8,15, 22	Harvested marketable leaves
	2	Topped plants, Offshoot-T applied
	4,17	Harvested suckers (unmarketable leaves)
	12,18	Orthene applied for hornworm control
	26	Soil samples taken for all treatment plots for soil analysis
	28	Last day of dispensing ozone
	29	Final harvest - all leaves, stalks and roots removed

19 and 20 May, McNair 944 seedlings were planted by hand in 44 plots. Each plot contained two rows of 10 plants each spaced 50 cm. Details of post-plant applications of fertilizer, insecticides and Offshoot-T for sucker control are shown in Table 4.1.4.1.

Soil tensiometers were installed at depths of 20 and 30 cm in each plot on 20 June. Tensiometer readings were recorded three times weekly and 2.5 cm of water was applied with drip tubing when readings for more than half of the tensiometers at 20 cm were greater than 50% of scale (-0.5 bars). Dates and rates of rainfall and supplemental irrigation are shown in Table 4.1.4.2.

Pollutant treatments. Twenty-four plots consisting of two rows with five plants each were chosen on 23 May. Initial measurements of leaf area (length x width) of all plant leaves and height per plant for all 10 plants per plot were made on 2 June for possible use in covariate analyses.

The experimental design was two replicates (randomized blocks) of the following eleven O_3 treatments: charcoal-filtered air chamber (CF); nonfiltered air chamber (NF) with no O_3 added; NF chambers with constant addition of 0.02, 0.04, or 0.06 ppm O_3 for 7 h (0900-1600 h EST) each day (NF + 0.02, NF + 0.04, NF + 0.06); proportional additions of O_3 for 7 h each day to achieve chamber concentrations of 1.3, 1.6, or 1.9 times the ambient O_3 concentration (NF7 x 1.3, NF7 x 1.6, NF7 x 1.9); and proportional additions of O_3 for 12 h each day (0900-2100 h EST) to achieve chamber concentrations of 1.3, 1.6 or 1.9 times ambient O_3 concentrations (NF12 x 1.3, NF12 x 1.6, NF12 x 1.9). A nonchambered plot (AA) was included for each replicate. All monitoring techniques were according to NCLAN protocols.

Chamber panels were installed by 30 May and O_3 dispensing began on 2 June when plants were about 20 cm tall and had an average of five expanded leaves. Dispensing continued until 22 August.

Dates and hours of suspended dispensing due to system malfunction are shown in Table 4.1.4.3.

Measurements. Leaves that were partially yellowed were harvested for each plant separately once weekly beginning on 27 June (Table 4.1.4.1.). Flowers and suckers were removed as they appeared (Table 4.1.4.1). Stems and roots were harvested on 29 August. All plant parts were bagged, dried for at least two days at 70 c, and weighed. Marketable leaves were defined as main-stem (non-sucker) leaves attached to the stem at 10-20 cm or higher above the ground.

The weight of marketable leaves per plant will be considered as the tobacco yield measure for NCLAN loss assessments.

Statistical analysis. An analysis of variance was conducted to determine the effect of blocks, treatments, plant position, and plant position x treatment interaction. Also, the impact of the variability of the initial (pre-treatment) leaf area and height of tobacco plants was determined. Results of these analyses showed that block differences were not significant, but both plant position effects and plant position x treatment interaction were significant. Also, both covariates were

Table 4.1.4.2. Dates, amounts, and pH of rainfall and dates and amounts of irrigation for the study to measure effects of exposure dynamics on tobacco response to O_3 at Raleigh, NC.

		Rainfall		Irrigation *
		cm	pH	cm
May	23			1.7
	26			0.9
	29			0.1
June	3			0.3
	4	1.1	4.2	
	5	0.1	4.4	
	8	4.3	4.2	
	17			2.5
	19	3.8	4.6	
	20	0.1	6.0	
	21	0.4	4.2	
	27	0.2	4.1	
	28	0.4	4.9	1.3
	30	1.0	4.1	
July	5	0.6	4.5	
	7			2.5
	12			2.5
	18			2.5
	22	0.2	4.6	2.5
	23	0.9	3.9	
	24	0.5	3.9	
	25	0.2	4.0	
	28			2.7
August	2	0.4	4.4	2.5
	9			2.5
	11	0.3	3.9	
	15			2.5
	23			2.5
	24	4.2	3.7	
Totals		18.7cm		26.9 cm

* All plots were irrigated.

Table 4.1.4.3. Periods of suspended O_3 dispensing due to rain or system malfunction for the study to measure effects of exposure dynamics on tobacco response to O_3 at Raleigh, NC.

Month	Day	Hours of suspended dispensing due to rain	Hours of suspended dispensing due to system malfunction*		
			Proportional Addition		Constant Addition
			7-h	12-h	7-h
June	5	0	7	7	
	8	0			7
	20	0	1.5	1.5	1.5
	23	0	3	8	3
August	9	0	3.5	8.5	3.5
Totals		0	15	25	15
Seasonal percent of time down		0%	2.4%	2.4%	2.4%

*System malfunction includes down-time due to line calibrations, monitor calibrations.

effective separately as measured by the reduction in experimental error. The effectiveness of the covariates were also assessed in fitting dose-response models.

The nature of the plant position and plant position by treatment interaction was investigated. Row (east-west) differences and variations of plant position within each row (north-south) were tested. A north-south linear trend accounted for a significant amount of the plant position effect, with the north plants producing a greater yield than the plants located in the southern part of the plot. No trend, neither an east-west nor north-south, could singly account for the plant position x treatment interaction.

The cause of the position by treatment interaction will be studied in further analyses. For analyses shown in this report, the mean over the plant positions of the treatment plot was taken.

The analyses revealed no advantage to using all 10 plants per plot over using six plants (three center plants per row) per plot. Because the end plants in each row were originally intended as border plants, they were not included in fitting dose-response models.

Pollutant dose-response models were fit to the marketable yield of the treatment plots. The effectiveness of the covariates was assessed; the presence of the initial leaf area in the model was significant and subsequently, the standard errors of the regression coefficients were improved. Thus, the final dose-response models for total marketable leaf weight were fitted with the initial leaf area as a covariate.

Dose-response models were calculated using data from all three O_3 addition methods. Regression models were produced using both 7-h and 12-h O_3 means. Polynomial dose-response models and a nonlinear model based on the Weibull probability distribution of sensitivities were used to produce dose-response surfaces. The polynomial response models allowed for the degree of polynomial necessary to fit the data. Further analysis will be conducted to determine the homogeneity of the dose-response curves for the constant, 7-h proportional, and 12-h proportional methods of dispensing.

4.1.4.3. Results

Pollutant doses. The mean seasonal 7- and 12-h O_3 concentrations for all O_3 treatments are shown in Table 4.1.4.4. The mean seasonal 7-h (0900 to 1600 h EST) and 12-h (0900-2100 h EST) O_3 concentrations in ambient air (AA) were 0.068 and 0.063 ppm, respectively. The mean seasonal diurnal fluctuations in O_3 concentrations for all O_3 treatments are shown in Table 4.1.4.5. Daily 7- and 24-h mean O_3 concentrations in AA are shown in Table 4.1.4.6.

Yield. Marketable leaf weight was from 46 to 53% of the total biomass with lower values occurring at higher O_3 concentrations, indicating a slightly greater effect of O_3 on leaf weight than on other plant parts (Table 4.1.4.7). Marketable leaf weight was from 81 to 90% of total leaf weight. Again the lower ratios appeared in the higher O_3 treatments (Table 4.1.4.7).

Table 4.1.4.4. Seasonal O_3 concentrations for the experiment to measure the effects of exposure dynamics on tobacco response to O_3 at Raleigh, NC *

O_3 Addition Treatment	7-hr/day Values (ppm)			1-hr day Values (ppm)			12-hr/day Values(ppm)
	Seasonal Means	Highest	Second Highest	Seasonal Means	Highest	Second Highest	Seasonal Means
None							
AA	.068	.109	.103	.078	.131	.122	.063
CF	.029	.052	.051	.043	.085	.084	.028
NF	.056	.093	.087	.067	.120	.114	.052
Proportional 7-hr							
NFx1.3	.087	.146	.135	.104	.176	.162	.070
NFx1.6	.103	.177	.166	.123	.207	.194	.080
NFx1.9	.123	.196	.195	.147	.227	.223	.091
Proportional 12-hr							
NFx1.3	.089	.162	.141	.106	.184	.168	.082
NFx1.6	.102	.178	.167	.123	.203	.192	.095
NFx1.9	.121	.209	.199	.146	.227	.221	.112
Constant 7-hr							
NF+0.02	.082	.122	.118	.094	.152	.139	.067
NF+0.04	.097	.139	.139	.111	.171	.152	.076
NF+0.06	.115	.159	.154	.129	.183	.177	.086

*All values are the mean of two readings.

Table 4.1.4.5. Diurnal fluctuations in O_3 concentrations for O_3 treatments for the experiment to measure the effects of exposure dynamics on tobacco response to O_3 at Raleigh, NC

Start Scan Time (EDT)	Seasonal Mean per Treatment Per Hour of Day*											
				Constant			NF 7			NF 12		
	AA	CF*	NF*	0.02	0.04	0.06	1.3	1.6	1.9	1.3	1.6	1.9
0950	.050	.017	.037	.059	.066	.080	.052	.068	.084	.053	.060	.068
1035	.058	.022	.046	.075	.090	.108	.073	.090	.110	.075	.086	.102
1120	.065	.026	.052	.080	.095	.113	.084	.101	.122	.086	.099	.118
1205	.070	.029	.057	.084	.101	.118	.090	.107	.129	.093	.108	.128
1250	.073	.031	.060	.086	.102	.120	.094	.111	.133	.097	.111	.131
1335	.073	.033	.061	.087	.103	.119	.095	.113	.133	.097	.111	.131
1420	.073	.034	.062	.088	.103	.121	.095	.113	.133	.098	.113	.131
1505	.073	.034	.061	.088	.104	.121	.095	.112	.132	.098	.113	.132
1550	.071	.034	.061	.088	.104	.121	.094	.112	.131	.096	.110	.129
1635	.073	.035	.063	.093	.101	.118	.099	.108	.124	.088	.105	.127
1720	.071	.035	.061							.088	.102	.120
1805	.068	.033	.060							.087	.101	.121
1850	.065	.030	.057							.092	.107	.127
1935	.061	.027	.051							.085	.098	.115
2020	.053	.021	.040							.070	.080	.092
2105	.044	.016	.031							.052	.060	.071
2150	.036	.013	.024							.042	.049	.058
2235	.033	.024	.024									
2320	.031	.023	.024									
0005	.030	.022	.025									
0050	.029	.022	.025									
0135	.029	.021	.024									
0220	.028	.021	.022									
0305	.025	.019	.020									
0350	.024	.018	.019									
0435	.024	.018	.018									
0520	.021	.016	.016									
0605	.019	.010	.015									
0650	.017	.009	.012									
0735	.017	.009	.013									
0820	.022	.011	.017									
0905	.028	.021	.021									

*Each value is the mean for two monitors except for data from 2235 to 0905 hr. For the hours from 2235 to 0905, AA values are the mean of two monitors and NF values are the mean of one monitor; for the hours from 2235 to 0520, CF values are 0.74 times AA values; for the hours from 0605 to 0820, CF values are 0.52 times AA values. Relationships between CF and AA were obtained from two years of comparisons under similar circumstances.

Table 4.1.4.6. Daily 7- and 24-h mean O_3 concentrations in ambient air during the study to measure the effects of exposure dynamics on tobacco response to C_3 at Raleigh, NC

	June		July		August	
Date	7 h * ppm	24 h ** ppm	7 h * ppm	24 h ** ppm	7 h * ppm	24 h** ppm
1			.037	.025	.027	.018
2	.066	.039	.062	.037	.035	.016
3	.068	.064	.062	.037	.026	.022
4	.052	.030	.061	.035	.060	.030
5	.059	.039	.041	.028	.072	.052
6	.054	.042	.064	.050	.063	.045
7	.050	.045	.058	.044	.068	.044
8	.066	.041	.078	.055	.061	.037
9	.077	.071	.085	.055	.083	.053
10	.069	.041	.081	.051	.081	.051
11	.077	.046	.057	.044	.074	.058
12	.071	.036	.078	.052	.060	.046
13	.109	.042	.087	.071	.046	.032
14	.096	.059	.095	.056	.053	.031
15	.094	.052	.103	.059	.077	.042
16	.074	.039	.096	.073	.080	.048
17	.070	.038	.087	.053	.084	.054
18	.073	.043	.076	.053	.065	.051
19	.046	.031	.073	.053	.087	.045
20	.056	.026	.096	.065	.087	.063
21	.073	.043	.076	.058	.088	.071
22	.051	.034	.073	.042	.083	.057
23	.067	.038	.058	.049	.095	.063
24	.093	.060	.057	.038	.048	.036
25	.092	.059	.063	.036	.050	.032
26	.074	.056	.067	.040	.065	.032
27	.060	.039	.067	.040	.070	.040
28	.040	.028	.052	.031	.057	.040
29	.044	.031	.048	.026	--	--
30	.039	.029	.057	.034	--	--
31	--	--	.041	.024	--	--

*Each value is the mean from 0900 to 1600 EST.
Each value is the mean for two monitors from 2 June to 6 July and for four monitors from 7 July to 28 August.

**The 24 hr means were calculated by prorating the daily 0900 to 1600 hr (7-hr) values and 1600 to 0900 (17-hr) values. The 17-hr values were the mean for two monitors.

Table 4.1.4.7. Growth and yield response of tobacco to chronic doses of O_3 added in constant or proportional amounts to ambient O_3 at Raleigh, NC*

Type of O_3 Addition	Seasonal means	Total Biomass/Plant (g)	Marketable Leaf Weight/Plant (g)	Total Leaf Weight/Plant (g)
None				
AA	.068	525	248	298
CF	.029	550	280	311
NF	.056	572	302	328
Constant				
NF + 0.02		482	250	283
NF + 0.04		485	236	276
NF + 0.06		445	211	256
Proportional 7-h				
NF7 x 1.3	.087	540	262	303
NF7 x 1.6	.103	495	236	278
NF7 x 1.9	.123	469	213	264
Proportional 12-h				
NF12 x 1.3	.082	437	218	252
NF12 x 1.6	.095	459	215	262
NF12 x 1.9	.112	410	187	236

*Each value is the mean of 12 plants (3 plants in 2 rows of 2 plots).

For each of the O_3-addition protocols, marketable leaf weights were less with increased O_3. At similar 7-h/day O_3 doses (Table 4.1.4.4) leaf weights were similar for the 7-h constant and the 7-h proportional additions (Table 4.1.4.7). However, the decreased yield for the 12-h proportional treatments compared to the 7-h proportional treatments indicates that additional effects of O_3 occurred between 1600 and 2100 hours (Table 4.1.4.7).

Comparisons between polynomial and Weibull relationships using the seasonal 7-h (0900 to 1600 EST) mean for all treatments or the seasonal 12-h (0900 to 2100 h EST) mean for all treatments are shown in Table 4.1.4.8. The 12-h mean was developed from the 7-h treatments by factoring in a common 5-h NF mean O_3 concentration for the 5-h period when O_3 was not added. Using the 7-h O_3 means, a significant quadratic relationship was found between O_3 dose and total marketable weight. Using the 12-h O_3 means, the polynomial analysis showed a significant cubic relationship between O_3 dose and marketable leaf weight (Table 4.1.4.8). The Weibull models showed similar relationships between O_3 dose and yield for both the 7- and 12-h means (Table 4.1.4.8).

4.1.4.4 Discussion

The different peak to mean ratios and overall exposure levels for the various treatments in the three types of exposure regimes probably simulates adequately those likely to occur in ambient air. For the 7-h regimes, there were no significant differences in tobacco response between the constant and proportional-to-ambient O_3 treatments. This result also occurred for soybeans at our site in 1982 (Heck et al. 1983a). Thus, in terms of plant response, constant or proportional exposure regimes appear to be equally adequate simulations of ambient O_3 regimes.

The original NCLAN protocol using 7-h exposures was adopted before it was possible to automatically control proportional-to-ambient O_3 additions. It was agreed that it would be unwise to add constant amounts of O_3 (as high as 0.06 ppm in some treatments) to low ambient O_3 levels which often occur after 1700 hr. Previous research has shown that plants are more physiologically active and more sensitive to O_3 in the morning than in the afternoon. The discovery that O_3 additions for 12 h caused tobacco yield decreases which were about 13% greater than 7-h O_3 additions raises the question of whether previous results from 7-h exposures have also underestimated O_3 effects. Further work is needed to directly compare results from 7- and 12-h exposures which will allow adjustment of data from previous experiments using 7-h exposure regimes. The results suggest that new NCLAN experiments should include 12-h proportional exposure regimes.

Table 4.1.4.8. Polynomial and Weibull equations for marketable leaf yield of 'McNair 944' tobacco exposed to chronic doses of O_3 added as constant or proportional amounts to ambient O_3 using either 7-hr per day or 12-hr per day mean O_3 concentrations as the independent variable for all O_3 treatments *

Equations derived from
7-hr O_3 Mean **

Polynomial

$$Y = \underset{(40.9)}{160.5} + \underset{(0.071)}{0.267}\ \text{area} + \underset{(729)}{649}x - \underset{(4585)}{10896}\ x^2$$

Weibull

$$Y = (153.5 + 0.350\ \text{area})\ e^{-\left(\frac{x}{0.169}\right)^{2.82}}$$

$$(35.3,\ \ 0.314,\ 0.015,\ 0.77)$$

Equations derived from
12-hr O_3 Mean **

Polynomial

$$Y = \underset{(74.6)}{25.5} + \underset{(0.071)}{0.194}\ \text{area} + \underset{(3409)}{10860}x - \underset{(52080)}{180785}x^2 + \underset{(244018)}{816096}x^3$$

Weibull

$$Y = (221.9 + 0.223\ \text{area})e^{-\left(\frac{x}{.152}\right)^{2.21}}$$

$$(36.0,\ \ 0.087,\ 0.015,\ 0.607)$$

---

* Regressions calculated using:
1) 7-hr O_3 mean (O_3 exposure 0900 to 1600 EST)
2) 12-hr O_3 mean (O_3 exposure 0900 to 2100 EST)

Y = total marketable leaf weight (dry weight - grams)
weight is mean of 6 plants per plot.

x = ozone dose (ppm) 7-hr and 12-hr O_3 mean, respectively.
area = initial (pretreatment) leaf area (mean per treatment) in cm^2.

** Standard errors for parameter estimates given in parenthesis. Weibull standard errors are given in order as ($\alpha 1$, $\alpha 2$, σ, c).

4.2. INFLUENCE OF SOIL MOISTURE ON O_3 DOSE RESPONSE RELATIONSHIPS

4.2.1. Influence of soil moisture level on response of soybeans to O_3 (SERCLAP)--Allen S. Heagle, R. B. Flagler, R. P. Patterson, V. M. Lesser, W. W. Heck, F. L. Mowry

4.2.1.1. Introduction

The amount of available soil moisture probably affects plant response to air pollutants more than any other environmental factor. The objective of this experiment was to determine O_3 dose-yield response relationships for soybeans grown with adequate soil moisture or with less than adequate soil moisture.

4.2.1.2. Materials and methods

Cultural. Seeds of soybeans, *Glycine max* (L.) Merr. cv 'Davis' were planted in rows spaced 50 cm on 16 June in a 0.24-ha field. The topsoil was approximately 30 cm of Norfolk loamy sand (fine-loamy, siliceous, thermic, Typic paleudult) which had been placed over approximately 15 cm of Appling sandy loam (clayey, Kaolinitic, thermic, Typic hapludult) in 1980. The soil was fertilized before planting according to soil test recommendations. Herbicide and pesticide applications are described in Table 4.2.1.1.

Plants emerged on 22 June and 30 plots were selected on 24 June based on adequate stand density and plant appearance. Plants in all plots were thinned to a stand of 19 plants per meter of row on 5 July. Each plot consisted of three rows which were from 2.7 to 3.0 m long.

Soil moisture was measured with tensiometers and with a neutron probe (Troxler Laboratories, Model 2651). Tensiometers were installed at a depth of 20 cm in each plot on 30 June. One neutron probe access tube was installed 15 cm from the center of the row in the NW quadrant of each chamber on 18 and 19 July. Tensiometer readings were recorded three times each week and neutron probe measurements were made weekly at depths of 22, 30, 45, 60, and 75 cm. Leaf psychrometry was used to measure total water potential of the youngest fully expanded trifoliolate leaves one or more times weekly. Two levels of soil moisture were obtained by different levels of irrigation with drip tubes installed adjacent to each row. Plots in the adequate-moisture treatment were irrigated with 2.5 cm of water when a reading of 50% of scale (-0.5 bars) was recorded on one tensiometer in any of the three replicates for a given O_3 treatment. Plots in the moisture-stress treatment were irrigated with 2.5 cm of water when a leaf water potential of -15 bars occurred in one plot of any of the three replicates for a given treatment. All plots of a given O_3 treatment were watered uniformly. Dates and rates of ambient rainfall and supplemental irrigation for each moisture treatment are shown in Tables 4.2.1.2 and 4.2.1.3, respectively.

Pollutant treatment. The experimental design was three replicates (randomized blocks) of four chamber O_3 treatments and one nonchambered (AA) treatment for each of two soil moisture levels (30 plots total). The four chamber treatments were charcoal-filtered air (CF), nonfiltered air (NF), and two NF treatments with addition of approximately 0.02 (NF + 0.20)

Table 4.2.1.1. Chronology of activities during the experiment to determine the effects of soil moisture on soybean response to O_3 at Raleigh, NC

Month	Day	Event
June	14	Treflan applied (0.38 liters/ha)
	15	Furadan applied (2.8 k/ha)
	16	Soybeans planted
	20	Plants emerged
	24	Plots chosen
	27	Chamber frames in place
	29,30	Top panels installed
	30	Irrometers installed
July	1	Bottom panels installed, fans turned on
	6	First harvest
	7	Began dispensing O_3
	12	Irrometers installed in non-irrigated plots
	13	Second harvest
	18,19	Neutron probes installed
	20	Third harvest
	26	Fourth harvest
August	1	Soil samples taken from each plot for nutrient analysis
	3	Fifth harvest
	9	Sixth harvest
	16	Seventh harvest
	17	Plictran applied (0.26 g/liter)
	23	Eighth harvest
	30	Ninth harvest
September	6	Tenth harvest
	13	Eleventh harvest
	20	Twelfth harvest
	27	Thirteenth harvest
October	4	Fourteenth harvest
	12	Fifteenth harvest
	18	Sixteenth harvest
	24	Last day of dispensing
	25	Seventeenth harvest
November	9,14	Final harvests
	15	Soil samples taken from all treatment plots for analysis

Table 4.2.1.2. Dates, amounts, and pH of rainfall during the experiment to determine the effects of soil moisture on soybean response to O_3 at Raleigh, NC

Date			Rainfall	
			cm	pH
July	1983	22	0.2	4.6
		23	0.9	3.9
		24	0.5	3.9
		25	0.2	4.0
August		2	0.4	4.4
		11	0.3	3.9
		24	4.2	3.7
September		2	0.1	3.6
		12	0.2	4.2
		14	4.0	4.6
		21	3.0	4.9
		30	0.3	4.2
October		5	0.5	4.2
		11	0.4	4.6
		13	1.1	4.9
		21	1.4	4.5
		23	4.4	5.6

Table 4.2.1.3. Months and dates of 2.5 cm of irrigation during the experiment to determine the effects of soil moisture on soybean response to O_3 at Raleigh, NC.

	Date per Month - 1983				
Adequate Soil Water Treatment	July	August	September	October	Total Waters Added (cm)
CF	15,20,28,30	4,7,10,13,16,19,22,28	1,5,8,11,13,20,29	4,9,20	55.9
NF	15,20,26,30	2,6,9,12,15,18,21,28,31	6,9,12,19,27	3,7,13,21	55.9
NF + 0.02	15,20,29	1,5,10,13,17,20,23,29	1,4,7,9,12,20,29	4,8,19	53.3
NF + 0.04	15,20,29	2,6,10,13,16,19,21,23,28	1,4,7,9,11,13,20,28	3,7,17	58.4
AA	15,20,28	1,6,10,13,16,19,22,28,31	3,6,9,11,13,21,29	4,9,19	55.9
Water Stressed Treatment					
CF	15 20	10 17	7		12.7
NF	15 20	10 17	7		12.7
NF + 0.02	15 20	10 17	7		12.7
NF + 0.04	15 20	10 17	7		12.7
AA	15 20	10 17	7		12.7

or 0.04 (NF + 0.04) ppm of O_3 for 7-h per day (0900 to 1600 EST). Chamber panels were installed and fans were turned on (0500 to 2100 EST daily) on 1 July. Ozone additions began on 7 July when plants had two trifoliolate leaves fully expanded. Ozone was added daily except during periods of rain and malfunction until 24 October when plants in all plots were physiologically mature. Dates and hours of suspended dispensing due to rainfall or system malfunction are shown in Table 4.2.1.4. Standard NCLAN protocols were used for dispensing and monitoring O_3.

Response measurements. Four plants were harvested from each plot starting on 6 July and continuing each 7 days until the 17th harvest on 25 October. The center row was harvested during the first six harvests leaving two 1-m sections of row in each plot containing undisturbed plants. The southern half of the east and west rows were removed during harvests 7-17 to establish growth curves and to make nitrogen and carbohydrate measurements. Plants in the undisturbed row sections were used to measure yield. Pods were removed from plants and weighed. Seeds were removed from pods by hand and weighed and the weight of 100 seeds per 1 m of row was measured. One CF water-stressed plot consistently showed much lower soil and leaf water levels than all other plots. This plot, located near the NE edge of the field, also had a sandier texture of soil than other plots and yield was lower than for all other water-stressed plots. For these reasons it was not used in the statistical analyses.

Statistical Analysis. Due to the large differences in the response of soybean yield to O_3 caused by moisture stress, the analysis of the data from the water-stressed and adequate-moisture plots were analyzed separately. As described earlier, one water-stressed plot was deleted from the analysis. Thus, an analysis was conducted accounting for this imbalance of the data.

An analysis of variance was obtained for both stressed and unstressed plots. For both moisture levels, the effects of block, row, and row x treatment interaction were non-significant. The O_3 effect was non-significant for the water-stressed plots but was significant for the adequate-moisture plots. Since the quadrant by treatment interaction was non-significant in both analyses, the mean of the two quadrants was used for further analysis.

4.2.1.3. Results

Pollutant doses. The mean seasonal O_3 concentration (7-h/day O_3 concentration during the period of O_3 dispensing) in ambient air (AA) was 0.57 ppm. The mean seasonal O_3 concentrations for the CF, NF, NF + 0.02 and NF + 0.04 treatment (water levels combined) were 0.029, 0.051, 0.076 and 0.098 ppm, respectively (Table 4.2.1.5). The mean seasonal diurnal fluctuations for AA and for the chamber treatments are shown in Table 4.2.1.6. Daily 7-(1000 to 1700 EDT) and 24-h O_3 concentrations in AA are shown in Table 4.2.1.7.

Yield. The season was abnormally dry with only 2.5 cm of rain between planting (16 June) and 24 August when 4.2 cm of rain fell (Table 4.2.1.2). Thus, we were able to control moisture levels with irrigation without requiring a rain exclusion system. Without irrigation, (Table 4.2.1.3) plants probably would have died.

Table 4.2.1.4. Periods of suspended O_3 dispensing due to rain or system malfunction during the experiment to determine effects of soil moisture on soybean response to O_3 at Raleigh, NC

Month	Day	Hours of Suspended Dispensing Due to Rain	Hours of Suspended Dispensing Due to System Malfunction *
July	11		1.00
	12		1.00
	24		1.50
	27		2.50
August	23		0.25
	26		1.25
	27		1.25
	28		2.00
	31		0.50
September	4		7.00
	6		2.00
	14	7.0	
	21	7.0	
	30	7.0	
October	11	7.0	
	21	7.0	
	23	3.5	
Totals		38.5	20.25
Seasonal percent of time down		5%	2.6%

* Time spent in calibrating monitoring tubes was included as system malfunction.

Table 4.2.1.5. Seasonal O_3 concentrations for the experiment to measure effects of soil moisture on soybean response to O_3 at Raleigh, NC

	7-h/day Values (ppm)			1-h/day Values (ppm)		
Treatment	Seasonal Means	Highest	Second Highest	Seasonal Means	Highest	Second Highest
CF^{+*}	.028	.060	.053	.036	.076	.064
CF^{-}	.031	.057	.056	.039	.077	.072
NF^{+}	.051	.097	.092	.060	.118	.107
NF^{-}	.052	.097	.092	.062	.119	.105
NF+0.02^{+}	.076	.129	.123	.088	.144	.140
NF+0.02^{-}	.076	.126	.122	.089	.142	.138
NF+0.04^{+}	.100	.154	.150	.115	.170	.164
NF+0.04^{-}	.097	.152	.146	.112	.170	.167
AA**	.057	.103	.100	.067	.125	.114

*All values are the mean of two sets of readings. + = adequate soil water; - = water-stressed.

**Means of four sets of readings (four monitors).

Table 4.2.1.6. Mean seasonal diurnal fluctuations in O_3 concentrations for various treatments in the experiment to measure effects of soil moisture on soybean response to O_3 at Raleigh, NC.

Start Scan	Seasonal Mean per Treatment Per Hour of Day (ppm) *				
Time (EDT)	AA	CF	NF	NF+0.02	NF+0.04
0950	.039	.019	.034	.054	.077
1035	.047	.024	.041	.066	.089
1120	.053	.027	.048	.072	.095
1205	.059	.030	.052	.077	.100
1250	.062	.032	.055	.080	.103
1335	.063	.033	.056	.081	.104
1420	.064	.033	.058	.082	.105
1505	.064	.033	.058	.082	.104
1550	.063	.033	.058	.083	.105
1635	.060	.030	.053		
1720	.059	.030	.052		
1805	.054	.027	.047		
1850	.047	.022	.039		
1935	.040	.018	.031		
2020	.033	.014	.024		
2105	.028	.011	.020		
2150	.022	.016	.020		
2235	.027	.020	.021		
2320	.026	.019	.021		
0005	.025	.019	.022		
0050	.025	.019	.022		
0135	.025	.019	.021		
0220	.024	.018	.019		
0305	.023	.017	.018		
0350	.021	.016	.017		
0435	.020	.015	.016		
0520	.018	.014	.014		
0605	.016	.008	.012		
0650	.014	.007	.010		
0735	.013	.007	.010		
0820	.017	.008	.013		
0905	.023	.011	.018		

* Each value is the mean for two monitors (plots) for each of two soil moisture levels for the period 7 July to 24 October 1983.

Table 4.2.1.7. Daily 7- and 24-hour mean O_3 concentrations in ambient air during the experiment to measure effects of soil moisture on soybean response to O_3 at Raleigh, NC.

	July		August		September		October	
Date	7-hr * ppm	24-hr ** ppm	7-hr ppm	24-hr ppm	7-hr ppm	24-hr ppm	7-hr ppm	24-hr ppm
1	--		.027	.018	.048	.036	.049	.024
2	--		.035	.016	.050	.034	.063	.032
3	--		.026	.022	.046	.021	.069	.042
4	--		.060	.030	.040	.023	.048	.037
5	--		.072	.052	.036	.025	.036	.029
6	--		.063	.045	.043	.035	.045	.031
7	.058	.044	.068	.044	.064	.048	.044	.019
8	.078	.055	.061	.037	.071	.046	.051	.032
9	.085	.055	.083	.053	.082	.054	.037	.023
10	.081	.051	.081	.051	.075	.051	.056	.040
11	.057	.044	.074	.058	.088	.050	.019	.017
12	.078	.052	.060	.046	.062	.032	.025	.021
13	.087	.071	.046	.032	.054	.032	.032	.028
14	.095	.056	.053	.031	.016	.020	.025	.013
15	.103	.059	.077	.042	.044	.027	.046	.016
16	.096	.073	.080	.048	.050	.022	.060	.024
17	.087	.053	.084	.054	.055	.038	.061	.024
18	.076	.053	.065	.051	.063	.027	.058	.024
19	.073	.053	.087	.045	.057	.036	.067	.032
20	.096	.065	.087	.063	.043	.029	.008	.013
21	.076	.058	.088	.071	.020	.016	.021	.018
22	.073	.042	.083	.057	.033	.020	.021	.020
23	.058	.049	.095	.063	.042	.031	.031	.025
24	.057	.038	.048	.036	.060	.030	.012	.007
25	.063	.036	.050	.032	.044	.023	--	--
26	.067	.040	.065	.032	.048	.025	--	--
27	.067	.040	.070	.040	.056	.044	--	--
28	.052	.031	.057	.040	.067	.046	--	--
29	.048	.026	.054	.034	.034	.027	--	--
30	.057	.034	.068	.038	.024	.021	--	--
31	.041	.024	.068	.040	--	--	--	--

* Mean concentrations from 0900 to 1600 hr EST. Each value is the mean for two monitors from 29 August to 24 October and for four monitors from 7 July to 28 August.

** The 17-hr values from 7 July to 28 August were a mean of two monitors and from 29 August to 24 October, were the reading from one monitor. the 24-hr means were calculated by prorating the daily 0900 to 1600 hr (7-hr) values and 1600 to 900 hr (17-hr) values.

The level of soil moisture stress established in the water-stressed plots was severe causing frequent wilting, occasional leaf loss, and stunted growth. In the CF treatments, seed yield of plants in the water-stressed plots was 43% less than that in the adequate-moisture plots (Table 4.2.1.8).

For the water-stressed plots, mean seed yields in the NF, NF + 0.02, and NF + 0.04 treatments were 34, 29, and 30% less, respectively, than in the CF treatment (Table 4.2.1.8). However, plot-to-plot variability, probably induced by small differences in soil moisture at extremely low overall moisture levels, was great and the analysis of variance showed no significant O_3 effect. We do not know whether the relatively low yield in the NF treatment was caused by a soil moisture x treatment interaction or by random plot-to-plot variability. While O_3 dose-response models were obtained for the drought-stressed plots, the standard errors for various model terms were very large and the regression equations were developed only to compare with those for the adequate-moisture treatment (Table 4.2.1.9).

For the adequate-moisture plots, mean seed yield in the NF, NF + 0.02, and NF + 0.04 treatments were 3, 20, and 29% less than that in the CF treatment (Table 4.2.1.8) and the O_3 effect was significant. For the adequate moisture treatment, the polynomial dose-response model showed a significant linear relationship between seed weight per 1-m row (yield) and O_3. The polynomial and Weibull dose-response models are shown in Table 4.2.1.9.

4.2.2. The Effects of O_3 and Soil Moisture Stress on Productivity of Two Soybean Cultivars, 1983 (SERCLAP)--H.E. Heggestad, T.J. Gish, E.H. Lee and W.L. Douglass)

4.2.2.1. Introduction

In 1982 experiments were performed to determine the effects of soil moisture stress on the response of soybeans to O_3 and SO_2 (Heggestad et al. 1985). Soil moisture stress increased the O_3 damage at ambient concentrations rather than tempering its impact as has been presumed. Consequently, there was need to repeat the study without SO_2 additions. The 1983 experiment investigating the O_3 and soil moisture interaction employed six ambient air (no chamber) plots and 30 open-top chamber plots. Some data from 1982 are provided to allow more meaningful comparison between the results of two years.

4.2.2.2. Methods and Materials

Cultural. Soybean, Glycine max. (L.) Merr. cvs. Williams-79 and Corsoy-79 were selected. Williams was used also the two previous years as it is the leading cultivar in the United States and adapted to Maryland as well as to North Central USA. Since NCLAN had data on the O_3 response of 'Corsoy' in Illinois, but none for 'Williams', 'Corsoy' was planted to compare its relative sensitivity to that of Williams.

Field Conditions. The field for the 1983 study was adjacent to one used in 1982. The field was divided in three blocks each containing 12 treatments; five levels of O_3 in chambers and an ambient air plot for

Table 4.2.1.8. Yield response of 'Davis' soybean to chronic doses of O_3 when grown under water-stressed or adequate soil water conditions at Raleigh, NC*

Ozone Treatment	Water-stressed			Adequate water		
	Seed wt (g)/m	Filled Pod wt (g)/m	Number of Seeds/m	Seed wt (g)/m	Filled Pod wt (g)/m	Number of Seeds/m
CF	256	366	1679	450	606	2605
NF	168	246	1273	436	588	2714
NF + 0.02	183	269	1379	358	493	2343
NF + 0.04	180	262	1347	320	436	2328
AA	208	302	1422	359	493	2289

*Each value is the mean of six 1-m sections of row.

Table 4.2.1.9. Polynomial and Weibull equations for seed yield of 'Davis' soybean exposed to chronic doses of O_3 when grown under adequate or water-stressed soil water conditions at Raleigh, NC.

Adequate soil water

Polynomial *

$$y = \underset{(343)}{5213} - \underset{(4960)}{20320x}$$

Weibull *

$$y = 4727\, e^{-\left(\frac{x}{0.156}\right)^{1.99}}$$

(575, 0.048, 1.63)

Water-stressed **

Polynomial *

$$y = \underset{(421)}{2421} - \underset{(587)}{754x}$$

Weibull *

$$y = 2540\, e^{-\left(\frac{x}{.232}\right)^{1.00}}$$

(2510, 0.358, 4.02)

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* y = seed yield (kg) per hectare
x = ozone dose (ppm) - seasonal 7-h/day mean

Standard errors for polynomial parameter estimates given in parenthesis. Weibull standard errors are given in order as [$\alpha(4727)$, $\sigma(0.156)$, $c(1.99)$].

** No significant response to O_3 was found for water-stressed soybean. Equations are given to compare with unstressed plots. In order to obtain a Weibull equation, c was set = 1.0 and α had an upper bound of 2600.

each of the two soil moisture regimes (-0.05 and -0.36 MPa, average value). The three blocks helped to remove the effects of a measurable gradient in sand and clay content as distances from a creek increased. Each plot was split with one row of each of the two cultivars. Plants in each main plot were supported with twine to avoid lodging. There were two companion plots for each of the 36 main plots. They were used to determine yield variability across each block for use in a covariant analysis.

The soil was a Codorus silt loam. Each plot was soil tested for P_2O_5, K_2O, Mn and pH. Lime, fertilizer and herbicide were applied before seeding. Lime applications depended on soil pH. Approximately 500 kg/ha of 5-15-30 fertilizer was broadcast uniformly over the field. The herbicide Treflan (trifluralin) at 1.75 l/ha provided excellent weed control.

Insecticides were first applied on 29 July. They included Plictran for mite control and Guthion for control of other insects. One application of Dipel (Bacillus thuringiensis) was also used.

Seeds were inoculated with Rhizobium using equal parts of USDA cultures 6, 110, and 142 and planted on 9 June. Rains in late May and early June caused a 2-week delay in seeding compared to the previous two years. The plants were thinned on 24 June to a 5-cm spacing in the row or 20 plants per m row. Row width (0.91 m) and plant spacing were the same in 1982 and 1983.

Prior to fertilization and planting, the field was graded in four beds 7.5 m wide and 90 m long. Each bed accommodated 9 of the 36 plots. The center 5.8-m width of the bed was raised about 5 cm and the edges were lowered about 12 cm to permit channels for surface water drainage from the plots to the border of the field. Rather than using plastic rain exclusion devices over the chambers as in 1982, plastic was placed over two-thirds of the soil surface between the rows. The clear polyethylene plastic was attached to 5 cm x 5 cm x 2.5 m wood strips. The plastic was extended beneath the chambers and the edges were buried with soil. All plastics were in place by 6 July, just before placing the chambers over the plots. A strip 30 cm wide in each plot row was left uncovered where water was added by drip irrigation. The drip tubing was placed on each side of the row about 12 to 15 cm from the plants.

Soil temperatures were monitored at the surface, and at 5- and 15- cm depths beneath the plastic for one plot in each of the moist and dry series. On hot days with ambient air temperatures above 35° C, the soil temperatures 15 cm beneath the plastic which was placed between the rows was about 1.0° C warmer than air temperature.

Soil Moisture, Irrigation

The soil water potential was above -0.05 MPa by the end of June because of above normal rainfall in May and June. Tensiometers were installed in all plots on 25 July at 25- and 45-cm depths beside the row of 'Williams'. Psychrometers were in place on 2 August at 12.5, 25 and 45 cm depths near the rows of Corsoy. Tensiometers were read daily between 7 and 8 a.m. from 25 July to 1 October. Between 3 August and 20 September the psychrometers were read daily. After 20 September, rains increased the soil moisture potentials beyond the range of the psychrometers. There were 12 days without values between 25 August and 7 September when the psychrometric microvoltmeter was returned to the company for service. Data were collected over a 48-day period for a total of 16 daily values at 3 soil depths in each of the 18 plots in the dry series. This soil moisture monitoring period covered some of the flowering and pod filling stages for the two cultivars.

In the moist series it was sometimes necessary to irrigate every day to maintain the soil water potentials at -0.05 MPa. No more than 1.5 cm of water was added per day except the first two irrigations on 18 and 22 July when 2.5 cm were added to the plots in the moist series. No water was added to plots in the dry series until 3 August when some plots were at - -0.5 MPa water potential. In the dry series, no more than 0.5 cm of water was applied on any day. Along with rainfall, this amount of water was adequate to maintain an average soil water potential of about -0.35 MPa (moderate stress) at the 25- and 45- cm depths. Rainfall during May through September and the amounts reaching the soil of plots with plasic barriers are shown in Table 4.2.2.1. The total amount of water supplied by rain and irrigation on a treatment basis and the mean soil water potentials are provided in Table 4.2.2.2. There was some variability in water requirements for treatment replicates perhaps due to differences in amounts of clay and sand. The variability is revealed by the standard errors for the means in Table 4.2.2.2.

Water amounts on each treatment in the two soil moisture regimes are expressed also as percent of normal rainfall for the months July, August and September (Table 4.2.2.3.). Under moist conditions, depending upon O_3 treatment, plants received as much as 60% more water than provided by normal rainfall whereas under dry conditions they received only about 30% as much as provided by normal rainfall. A comparison was made of water received on the plots in the two soil moisture regimes for the two years 1982 and 1983 (Table 4.2.2.4.). Although the two seasons were different in rainfall amounts, the measurements in soil water potentials showed that the two years were comparable in the amount of water received.

Ozone Exposure Treatments. The chamber fans were started on 11 July. The O_3 exposures began 23 July and continued for 63 days when all plants were at harvest maturity. Exposures of 7 h a day were possible on 54 days of the 63-day period. On 4 days there were 3-1/2 h of exposure, on 2 days only 2 h of exposure, and on 3 days there was no exposure. The O_3 generator failed on 2 days requiring a trip to the Griffin factory in New Jersey for servicing. Another generator was loaned during the repair period. On three different dates during the summer, exposures were discontinued for a few hours while the sample lines were calibrated.

The O_3 was monitored with a Thermo Electron Model (TECO) 49 and a Dasibi 1003 PC instrument. The instruments were calibrated with another Dasibi 1003 PC instrument. Each O_3 monitor was used to sequentially monitor 18 plots on an hourly basis with 3 minutes per plot. The probes for air sampling were in the center of the plots and just above the plant canopy. A Bendix 8002 O_3 monitor was used to continuously monitor ambient air at the plant site about 3 m above the ground. The sample lines were checked to determine loss of O_3 between the plots and the O_3 monitors in the trailer. The range in O_3 loss for the chambers was

Table 4.2.2.1. Ambient rainfall compared to the amount received by plots having partial exclusion facilities

Month		Rainfall (cm)		
		Normal*	1983	On Plots**
May		9.7	12.4	12.4
June		8.5	16.1	16.1
July		10.5	2.2	1.3
August		11.7	11.9	3.9
September		8.4	6.7	2.2
	Total	48.8	49.3	35.9

*Coverage rainfall for the month

**Two-thirds of rainfall excluded from all plots between 6 July and 1 October.

Table 4.2.2.2. Irrigation water applied on each treatment and mean soil water potentials for moist and dry soil regimes.*

O_3 Treatment	O_3 7 h/day 63 days Avg. (ppm)	Moist Soil		Dry Soil	
		Water Applied (cm)	Soil H_2O Potential (MPa)	Water Applied (cm)	Soil Water Potential (MPa)
CF	.019	41.9 ± 5.8	-.056 ± .005	4.3 ± 0.4	-0.444 ± .043
NF	.052	43.3 ± 5.7	-.058 ± .007	2.6 ± 0.5	-0.322 ± .021
NF + .03 ppm	.079	35.1 ± 2.6	-.049 ± .001	1.2 ± 0.4	-0.388 ± .036
NF + .06 ppm	.107	28.9 ± 4.0	-.048 ± .002	1.2 ± 0.4	-0.360 ± .054
NF + .09 ppm	.132	27.3 ± 3.1	-.050 + .002	0.8 ± 0.4	-0.324 ± .035
Open plots AA	.056	23.8 ± 2.8	-.046 ± .001	0.7 ± 0.1	-0.317 ± .035

*Means for 3 replications and SE of means shown. Soil water potentials are means for 25- and 45-cm depths. First irrigation in moist series was 18 July and in dry series was 3 August. After irrometers and psychrometers were in place on 25 July and 2 August, respectively, no more than 1.5 cm was applied to a plot in any one day in the moist series and 0.5 cm for the dry series. The moist series received 2.5 cm on 18 and on 22 July.

Table 4.2.2.3. Water amounts on plots according to treatment expressed as percent of normal rainfall for each month

O_3 Treatment	July		August		September		Average	
	Moist %	Dry %	Moist %	Dry %	Moist %	Dry %	Moist %	Dry %
CF	101	12	193	49	192	56	162	39
NF	105	12	216	42	171	45	164	33
NF + .03 ppm	100	12	179	44	132	26	137	27
NF + .06 ppm	97	12	143	41	112	30	117	28
NF + .09 ppm	97	12	143	36	93	32	111	27
AA	85	12	121	38	96	27	101	26
Average	98	12	166	42	133	36	132	30

Table 4.2.2.4. Cumulative amount of water per plot by months in moist and dry soil series in 1982 and 1983*

	Moist Series		Dry Series		Dry Compared to Moist	
Month	1982 (cm)	1983 (cm)	1982 (cm)	1983 (cm)	1982 (%)	1983 (%)
May	6.9	12.4	6.9	12.4	100	100
June	21.4	28.5	21.4	28.5	100	100
July	39.5	38.7	28.1	29.8	71	77
August	57.1	58.1	32.4	34.7	57	60
September	73.7	69.3	42.7	37.7	58	54
				Average	77.2	78.2

*Means for 3 replications and for all treatments.

between 2 and 18% with an average of 8%. The O_3 exposure data were adjusted to reflect line loss.

Biological responses: Plant maturity for each cultivar was dated on a plot-by-plot basis during the season using the Fehr classification. Physiologic maturity of the cultivar Williams at the time O_3 exposures were initiated was about the same in 1982 and 1983. Although there was about a 2-week delay in adding O_3 in 1983, the seeding was delayed 2 weeks because of wet soil in late May and early June. The cultivar Corsoy began to flower on 11 July, at the time CF and NF air treatments were started but 15 days before beginning the O_3 exposure treatments. 'Williams' began flowering on 19 July. Since both Corsoy and Williams are indeterminate in flowering, most of the flowering was after initiating the O_3 treatments.

Foliar injury was assessed by measuring the height to the first node with a fully green leaf and comparing it with total plant height on four plants of each of the two cultivars per plot; i.e., 10% of total harvested plants per plot. The measurements were made at 2-week intervals beginning 2 August. In addition, foliar injury per plant was assessed by assigning index values of 0 to 100, reflecting % of leaves showing O_3 or yellowing symptoms, on a plot basis. Stomatal resistance data were taken with a LICOR autoporometer and leaf water potentials with a Scholander pressure chamber (PMS, Corvallis).

Leaf area and dry weight measurements were made on 16 August taking terminal leaflets from a recently fully expanded leaf near the top of the plant canopy on each of five plants of each cultivar. Williams was sampled in all plots, Corsoy only in the CF and NF treatments.

Plots were harvested when all pods were brown. Plants were cut at the ground, the pods removed and seeds threshed from the pods. Data were taken on stem weight, pod weight, and seed weight after allowing time to air dry. Seed weights were adjusted to 13% moisture content.

Seed quality was evaluated by determining oil and protein content, using light-absorbing techniques developed by Karl Norris, Chief of the USDA Instrumentation Laboratory at Beltsville, Maryland.

4.2.2.3. Results

Seasonal Climate. Rainfall was above normal in May and June, delaying land preparation and seeding about two weeks (Table 4.2.2.1). During June soil water potentials were more than -0.05 MPa; consequently even though rainfall was much below normal in July, drought stress developed gradually. The amounts of water applied varied with O_3 treatments and the targeted soil water potentials (Tables 4.2.2.2., -3. and -4.). As the O_3 dose increased there was less need for water especially in the moist series (Table 4.2.2.3.). In the dry series the three treatments with supplemental O_3 received about the same amount of water while the CF and NF air treatments required more water. The total amount of water received from irrigation and rainfall in 1982 and 1983 was very similar (4.2.2.4.). The similarity can be attributed to the amounts required to grow soybeans at the indicated soil water potentials. In 1983 the dry plots received an average of 30% of normal rainfall from July through September, whereas the moist series averaged 32% more than normal rainfall (Table 4.2.2.3.). There was more variation in irrigation water applied per treatment in the moist soil series than in the dry series. The AA treatment in the moist and dry series required less water to maintain the same soil water potentials as in NF air; i.e., 38% and 21%, respectively, less water. This suggests a chamber effect causing an increase in evapotranspiration in the chambers. The AA plots had less growth than the NF plots, also; i.e., 23% less yield under moist conditions and 7% less in the SMS series.

Maximum and minimum temperatures for the months May through September in 1982 and 1983 are provided in Table 4.2.2.5. In 1983, all months of the growing season were warmer than in 1982. In August the mean maximum and mean minimum temperature differences were higher by 5.2° F. The maximum temperature was 103° F in 1983 compared to 95° F in 1982.

Ozone data

The data on O_3 were first summarized manually by obtaining hourly means from the chart recorders. The daily 7- and 24-h means are plotted in Figure 4.2.2.1. The ambient O_3 values were higher in 1983 than 1982. On eight dates the 7-h means were 0.10 ppm or higher whereas none exceeded 0.08 ppm in 1982. As may be noted from ambient air O_3 data for 12 days in mid-July (to left of Figure 4.2.2.1.) O_3 levels were higher on July 15 and 16 than any time later in the season. This is the period when chambers were turned on but O_3 additions were not started. However, the CF and NF treatments were maintained for the additional 12 days. The season diurnal O_3 values for all treatments, including the ambient air plots, are provided in Figure 4.2.2.2. In Table 4.2.2.6., the O_3 dose is characterized in several ways: the seasonal mean 7-h values for each treatment, the highest and second highest 7-h/day value, the highest and second highest hourly mean, and the seasonal daily maximum hourly means for all replicates of each treatment. The peak 7-h and 1-h values for each treatment were higher in 1983 and the 7-h means for the season were somewhat higher in 1983.

Injury. Leaf injury was evaluated to show both chronic O_3 injury and yellowing. The latter reflected primarily foliar changes due to normal senescence and drought. Injury values were higher for 'Corsoy' than 'Williams', perhaps due in part to earlier maturity (Table 4.2.2.7.). O_3 injury was somewhat greater in the moist series.

Yield. Yields for CF and NF air treatments in 1983 averaged 5962 kg/ha compared to 4383 kg/ha in 1982. The higher yields in 1983 were probably due to the change in the field location. In 1983 we used a plot area that had been planted in corn and rye cover crops for 2 years. All of the biomass produced by the cover crops was incorporated in the soil. The field was adjacent, however, to the one used in 1982, consequently the soil characteristics were otherwise very similar.

Mean square values for yield, seed size, seed numbers, pod numbers and plant height are presented (Table 4.2.2.8.). There were significant effects of the O_3 treatments on all variables evaluated. Soil moisture stress caused signficant effects on plant height at harvest and on seed size. Cultivar differences were highly significant for yield, seed size, and plant height. Perhaps of greatest interest was the significant

Table 4.2.2.5. Mean of the daily maximum and minimum temperatures, May through September 1982 and 1983, Beltsville, MD

Month	1982 Means		1983 Means	
	Max F	Min F	Max F	Min F
May	77.0	52.6	72.8	50.5
Temperature extreme	87	37	85	36
June	79.5	64.0	82.8	61.5
Temperature extreme	89	51	93	51
July	86.8	66.2	88.7	65.0
Temperature extreme	95	55	97	52
August	83.0	61.2	88.2	66.2
Temperature extreme	91	39	103	53
September	78.0	56.2	81.6	56.2
Temperature extreme	89	43	98	37
Average	80.9	60.0	82.8	59.9

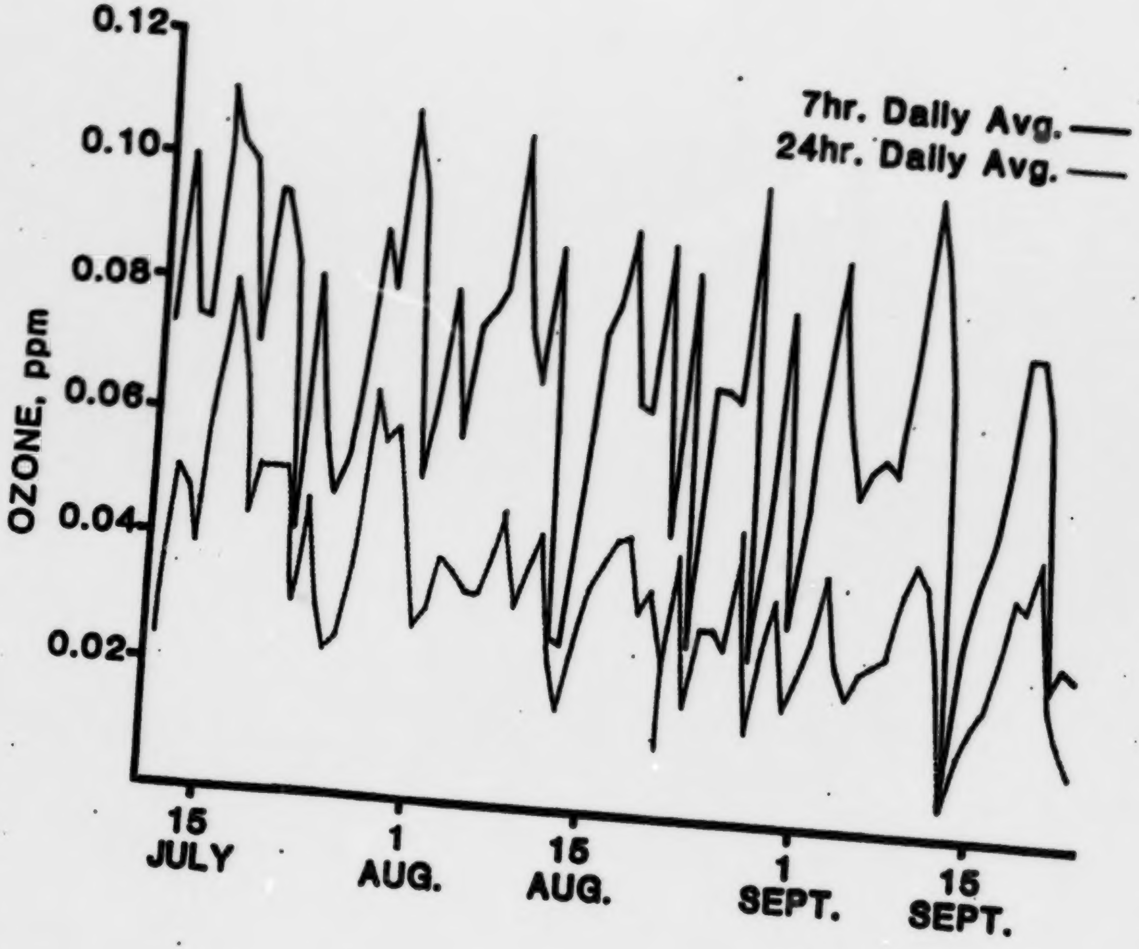

Figure 4.2.2.1. Ambient 7-h (0900-1600 EST) and 24-h O_3 data from 11 July to 23 September sampled at 3 m above ground adjacent to soybean field site.

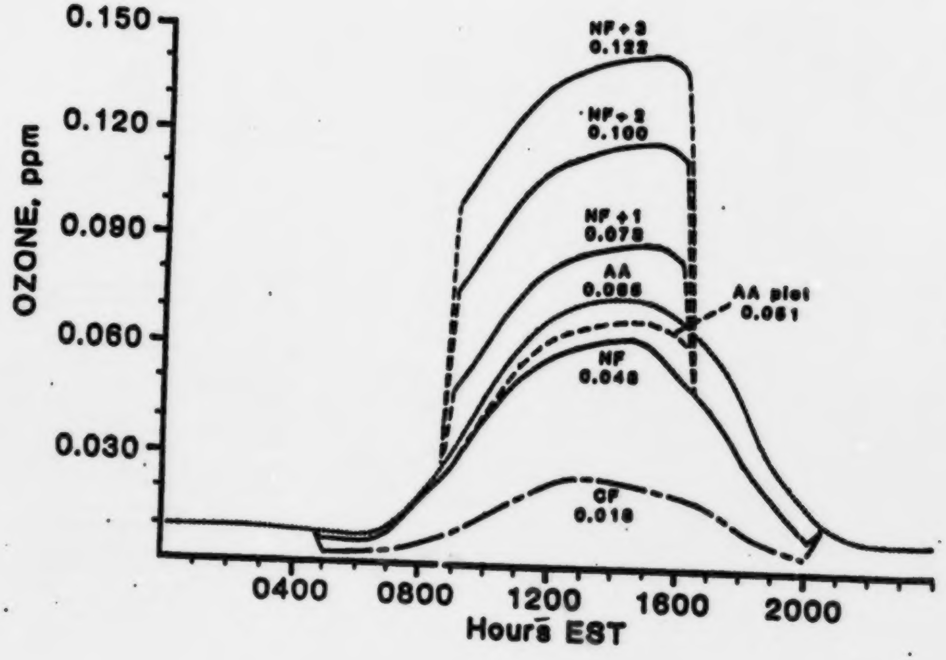

Figure 4.2.2.2. Seasonal mean diurnal fluctuations in O_3 levels and seasonal 7-h/day means from 23 July to 23 September for various treatments in the soybean study, Beltsville, MD.

Table 4.2.2.6. Characterization of O_3 concentrations during period of O_3 exposure, from 23 July - 23 September in 5 treatments averaged across 3 replications and 2 levels of soil moisture in the soybean study at Beltsville, MD*

O_3 Treatment	Fumigation 7-h/d Means for Season	7-h Exposure Period Means		Daily 1-h Max		Daily 1-h Max Average for Season ppm
	63 days ppm	Highest ppm	Second Highest ppm	Highest ppm	Second Highest ppm	
CF	0.019 ± .001	0.026	0.023	0.057	0.055	0.032
NF	0.052 ± .001	0.091	0.084	0.121	0.117	0.067
NF + 0.03 ppm	0.079 ± .001	0.122	0.118	0.154	0.151	0.098
NF + 0.06 ppm	0.108 ± .001	0.159	0.152	0.185	0.183	0.134
NF + 0.09 ppm	0.132 ± .002	0.194	0.179	0.222	0.213	0.164

*Ambient air plots without chambers had a mean value of 0.056 ppm or 7% higher than for NF air in chambers. The 7-h ambient air value taken 3 m above ground on the north side of the field was 0.065 ppm or 16% higher than in the ambient air plot and 25% higher than for NF air in chambers. The diurnal hourly values for these locations may be compared in Figure 4.2.2.2. The ambient air values at the field location were almost the same as a nearby greenhouse about 2 km away.

Table 4.2.2.7. Ozone injury and yellowing on two soybean cultivars as related to O_3 and soil moisture stress on September 7, 1983

Moisture Stress	O_3 Treatment	Season Mean 7-h O_3 Conc. (ppm)	% Leaves with Symptoms			
			O_3 Injury		Yellowing	
			Williams	Corsoy	Williams	Corsoy
No Stress						
	CF	0.019	1	7	0	4
	NF	0.052	30	50	10	13
	NF + .03 ppm	0.079	50	75	12	27
	NF + .06 ppm	0.107	67	90	23	53
	NF + .09 ppm	0.132	83	95	50	93
	AA	0.056	25	52	6	17
		Average	43	61	17	34
Moderate Stress						
	CF	0.019	1	2	2	7
	NF	0.052	20	37	10	27
	NF + .03 ppm	0.079	32	70	15	43
	NF + .06 ppm	0.107	62	91	20	86
	NF + .09 ppm	0.132	78	95	45	97
	AA	0.056	20	40	10	27
		Average	35	55	17	47

Table 4.2.2.8. Summary of mean squares from ANOVA test on soybean yield, seed size, seed numbers, plant height and pod numbers.

Source Total	df (71)	Yield kg/ha ($x10^3$)	Seed Size (g/100 seeds)	Seed Number ($x10^9$)/ha	Height (cm)	Pods (#)
O_3	5	16,583***	44.6***	189,442***	1160***	1023**
Rep.	2	61	1.0	9,095	126*	77
Soil Moisture (SM)	1	44	1.6*	3,153	3682***	245
O_3 x SM	5	1,073*	1.0*	25,047*	221*	238
Error a†	22					
Cultivar (C)	1	24,229***	1429.4***	4,076	139*	12,760***
C x O_3	5	189	1.2**	3,517	25	134
C x SM	1	216	27.3***	45,579**	67	117
C x O_3 x SM	5	376	0.5	15,238*	16	86
Error b†	24					
R^2		0.97	0.99	0.92	0.96	0.87
CV		8.3	2.6	8.0	3.8	18.3

* = $P < .05$, ** $P < .01$, *** $P < .001$

† Error a = O_3 x SM x Rep.

Error b = Total for interactions involving Rep and C.

interaction between O_3 and soil moisture for all variables except pod numbers. The R^2 values were high for all variables, being highest (0.99) for seed size. The coefficients of variability (cv) were less than 10 for all variables except pod numbers.

The average yields for the six O_3 treatments are provided along with comparisons on a percentage basis to the yields in CF air (Table 4.2.2.9). 'Corsoy' was less sensitive to ambient O_3 (NF) when soil moisture stress was avoided. Yield reduction in the NF treatments for wet soil for 'Corsoy' and 'Williams' was 7.4 and 13.2%, respectively. Under dry soil conditions the yield reductions were 23.5 and 10.6, respectively. In the AA plots 'Corsoy' yielded 27% and 31% less than in CF air under moist and dry conditions, respectively. The comparable values for 'Williams' were 35% and 14%. Chamber effects are indicated by the data. When O_3 was increased over that in ambient air, yields in the drought-stressed plots were about 10% higher than for plots grown without soil water stress. It appears that soil moisture stress reduced O_3 impact. There was a lack of protection at ambient O_3 concentrations (NF). 'Corsoy' was affected more by the combination of the two stresses than 'Williams' since, in CF air, irrigation had little effect on seed production. Apparently 'Corsoy' acclimated very well to drought stress in CF air; that is, there was no yield decrease even though the soil was drier at the control depth than in NF air (-.444 vs -.322 MPa, respectively). This is similar to the results obtained with 'Forrest' and to lesser extent with 'Williams' in 1982.

As with yield, increasing O_3 dose decreased seed size (Table 4.2.2.10.). The percentage reduction in seed size was similar for the two cultivars; however, seeds of 'Williams' are normally about 15% larger than 'Corsoy' seeds. Seed numbers were reduced as well as seed size by O_3 dose (Table 4.2.2.11.). The highest concentration of O_3 reduced seed numbers an average of 32% for cultivars and the soil moisture regimes, whereas seed size was reduced 27%. Total yields were reduced 50% by the highest O_3 dose (Table 4.2.2.9.).

Other Variables. Some data are provided on stomatal conductance and transpiration for the O_3 treatments with and without soil moisture stress (Table 4.2.2.12.). The increase in O_3 exposure dose decreased both variables similarly on moist and dry soil.

Leaf area and dry weights were obtained for all plots on 16 August (Table 4.2.2.13.). Ozone and drought stress decreased both parameters. Dry weight per leaflet was reduced more by O_3 exposure than was leaf area. The highest O_3 dose reduced the area of each terminal leaflet about 20% compared to 35% for dry weight.

Midday xylem leaf water potentials were obtained during August and the first week of September. During August in the moist and dry soil series they averaged -0.45 ± 0.02 and -0.55 ± 0.03 MPa, respectively. Although the leaf water potentials were relatively high in both series, there was an 18% difference due to differences in soil water potentials in the two moisture regimes. There was almost no effect of O_3 treatment on the leaf water potentials, considering the available data. By 31 August, one replication of the dry series treatments averaged -0.88 ± .11 MPa, indicating the moisture stress was increasing over that measured earlier in the month.

Table 4.2.2.9. Yields of two cultivars exposed to increasing O_3 doses and grown with and without soil moisture stress

O_3 Treatment*	O_3 7-h/day 63 days (ppm)	Percent of Yields in CF Air (%)				Yield (kg/ha)			
		Wet soil		Dry Soil		Wet Soil		Dry Soil	
		Corsoy	Williams	Corsoy	Williams	Corsoy	Williams	Corsoy	Williams
						kg	kg	kg	kg
CF	.019	100	100	100	100	5866	7595	5769	6439
NF	.052	92.6	86.8	76.5	89.4	5431	6595	4413	5755
NF + .03 ppm	.079	60.8	70.8	72.7	80.1	3569	5376	4193	5157
NF + .06 ppm	.107	46.2	54.8	60.0	72.8	2711	4162	3464	4688
NF + .09 ppm	.132	44.6	45.3	52.6	55.8	2617	3442	3034	3596
AA	.056	73.2	65.0	68.9	85.7	4294	4937	3976	5518

*CF = Charcoal filtered; NF = Nonfiltered ambient air; AA = Plots without chambers.

Table 4.2.2.10. Seed size of two cultivars exposed to increasing O_3 doses, and grown with and without soil moisture stress.

O_3 Treatment*	O_3 7-hr/day 63 days (ppm)	Percent of Seed Size in CF Air				Seed Size (g/100 seed)			
		Wet Soil		Dry Soil		Wet Soil		Dry Soil	
		Corsoy	Williams	Corsoy	Williams	Corsoy g	Williams g	Corsoy g	Williams g
CF	.019	100	100	100	100	17.9	21.0	16.6	21.3
NF	.052	92.2	94.3	94.0	95.3	16.5	19.8	15.6	20.3
NF + .03 ppm	.079	83.2	87.1	88.6	94.4	14.9	18.3	14.7	20.1
NF + .06 ppm	.107	73.2	79.5	80.7	84.0	13.1	16.7	13.4	17.9
NF + .09 ppm	.132	68.2	71.4	78.9	73.7	12.2	15.0	13.1	15.7
AA	.056	87.7	93.8	92.8	95.3	15.7	19.7	15.4	20.3

*CF = Charcoal filtered; NF = Nonfiltered ambient air; AA = Plots without chambers.

Table 4.2.2.11. Number of seed for two cultivars exposed to increasing O_3 doses, and grown with and without soil moisture stress.

O_3 Treatment*	O_3 7-hr/day 63 days (ppm)	Percent of Seed Numbers in CF Air				Seed Numbers/ha (thousands)			
		Wet Soil		Dry Soil		Wet Soil		Dry Soil	
		Corsoy	Williams	Corsoy	Williams	Corsoy	Williams	Corsoy	Williams
CF	.019	100	100	100	100	32,791	36,116	34,621	30,273
NF	.052	100.3	92.4	81.7	90.8	32,888	33,364	28,301	27,474
NF + .03 ppm	.079	73.1	81.3	82.6	84.7	23,954	29,351	28,608	25,635
NF + .06 ppm	.107	63.1	69.0	74.8	86.4	20,704	24,910	25,893	26,171
NF + .09 ppm	.132	65.9	63.4	67.0	75.8	21,614	22,896	23,206	22,939
AA	.056	83.5	69.5	74.4	89.8	27,384	25,101	25,742	27,187

*CF = Charcoal filtered; NF = Nonfiltered ambient air; AA = Plots without chambers.

Table 4.2.2.12. Stomatal conductance (abaxial plus adaxial) and transpiration of soybean leaves as related to O_3 dose and soil moisture stress, 10 August 1983*

	Stomatal Conductance		Transpiration	
O_3 Treatment	Moist Soil (cm/s)	Dry Soil (cm/s)	Moist Soil (g/cm/s)	Dry Soil (g/cm/s)
CF	2.8 ± 0.1	2.4 ± 0.3	26.2 ± 0.3	24.1 ± 0.8
NF	2.3 ± 0.2	1.9 ± 0.2	23.3 ± 1.0	20.7 ± 1.9
NF + .03 ppm	1.8 ± 0.4	1.7 ± 0.4	20.4 ± 1.6	21.0 ± 1.9
NF + .06 ppm	2.2 ± 0.1	1.6 ± 0.3	22.5 ± 0.9	16.0 ± 2.3
NF + .09 ppm	1.4 ± 0.2	0.9 ± 0.1	15.3 ± 1.7	12.5 ± 1.0
AA	1.9 ± 0.3	2.0 ± 0.3	16.3 ± 1.8	19.5 ± 1.9

*Fully expanded leaves near top of plant canopy, one leaf on each of four plants in one replication. Day sunny, 29°C, R.H. 58%, light 1920 $\mu Em^2/s$. Stomatal conductance values may be high due to improper calibration of porometer but relative differences would be maintained. Values are shown ± standard errors.

Table 4.2.2.13. Effects of O_3 and soil moisture stress on leaf area and dry weight, 16 August, for 'Williams' soybeans*

O_3 Treatment	Leaf Area		Leaf Dry Weight	
	Soil Moist (cm^2)	Dry (cm^2)	Soil Moist (mg)	Dry (mg)
CF	64 ± 3	61 ± 2	316 ± 20	322 ± 12
NF	61 ± 2	51 ± 3	328 ± 18	252 ± 22
NF + .03 ppm	59 ± 7	53 ± 5	274 ± 26	260 ± 30
NF + .06 ppm	54 ± 2	54 ± 4	238 ± 10	248 ± 32
NF + .09 ppm	54 ± 4	48 ± 3	216 ± 2	196 ± 2
AA	61 ± 9	49 ± 2	268 ± 16	214 ± 22

*Measurements made on terminal leaflets from a recently fully expanded leaf near the top of the plant canopy on each of 5 plants per plot.

A regression analysis revealed a significant linear relationship between yield, O_3 dose and soil water potentials for 'Williams' whereas with 'Corsoy' a significant cubic response was indicated (Table 4.2.2.14.). Soil water potentials are negative values in the equations. The predicted yield values as related to O_3 dose for dry and moist soil conditions are shown by Figures 4.2.2.3. and -4. In both figures yield decreases were greater for drought than moist soil conditions at the low O_3 concentrations; whereas, at the highest ozone concentrations yields were reduced most when soil moisture stress was avoided. Only Corsoy showed a greater yield reduction under drought conditions (Table 4.2.2.9.).

'Corsoy's' lack of response to irrigation in the charcoal-filtered air plots is of interest since it was similar to that obtained with Forrest and 'Williams' in the 1982 experiment.

Weibull equations relating yield (kg/ha) to seasonal 7-h/day mean O_3 concentrations are presented in Table 4.2.2.15. These equations were developed by Dr. W. W. Cure, Department of Botany, North Carolina State University, Raleigh.

Seed quality as reflected by percent protein and oil content was not affected by O_3 exposure or drought. This is different than that reported for 'Corsoy' by Kress and Miller (1983) even though yield reductions related to O_3 treatment were comparable in the two experiments.

4.2.2.4. Discussion

A satisfactory measurement of the energy status of soil moisture, at least in the primary root zone, is critical to any experiment involving soil moisture and O_3 stress. Soil psychrometers permit measurement *in situ* for soil water potentials less than -.1 MPa. Tensiometers are effective only at potentials greater than -.08 MPa. Factory calibration of the psychrometers was inadequate for our use since they are calibrated at only one temperature and potential. About 80% of the psychrometers had R^2 values satisfactory for field work (i.e., $R^2=0.85$). The calibration procedures were made available to the EPA Quality Assurance officer for the NCLAN program. To further check on accuracy of measurements, duplicate psychrometers were placed at various depths in some plots. Values of duplicates were similar.

The effects of O_3 on soybeans in normal field situations may be greater than indicated by the yield reductions in our no-water stress series. In this series the soil water potentials were checked every day and water was added by drip irrigation, every day if needed, to maintain the targeted water potentials at the 25- to 45-cm soil depth. In experiments prior to 1982 at Beltsville, the soil water potentials were not checked as regularly and the supplemental irrigation was not applied with a drip irrigation system. Even in a season with normal rainfall each month, the soil water potentials would be lower at times than under our 1982 and 1983 experimental conditions. In 1983 the plants in the moist series received an average of 32% more water than normal rainfall (Table 4.2.2.3.). It is expected that a level of soil moisture stress less than in our experiments would interact also with ambient O_3 to decrease yield at least for some cultivars. Also, if the soil moisture stress was very severe the effects of O_3 stress might seem negligible.

Table 4.2.2.14. Regression equations for seed yield data using O_3 concentrations and soil water potentials for each plot*

Williams

$$\text{Yield} = 8493.8 - 39.4\,(\text{ozone}) + 355.5\,(\text{bars}) - 3.87\,(\text{ozone} \times \text{bars})$$

Corsoy

$$\begin{aligned} \text{Yield} = {} & 395 - 32.0\,(\text{Adjust } O_3) + 0.119\,(\text{Adjust } O_3)^2 \\ & + 0.0017\,(\text{Adjust } O_3)^3 - 42.3\,(\text{Adjust bar}) \\ & - 10.7\,(\text{Adjust } O_3)\,(\text{Adjust bar}) \\ & + 0.0083\,(\text{Adjust } O_3)^2\,(\text{Adjust bar}) \\ & + 0030\,(\text{Adjust } O_3)^3\,(\text{Adjust bar}) \end{aligned}$$

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*See predicted yield dose response in Figures 4.4.4.3 (Williams) and 4.4.1.4 (Corsoy), O_3 is in ppb, bar = 10 times megapascal (MPa)

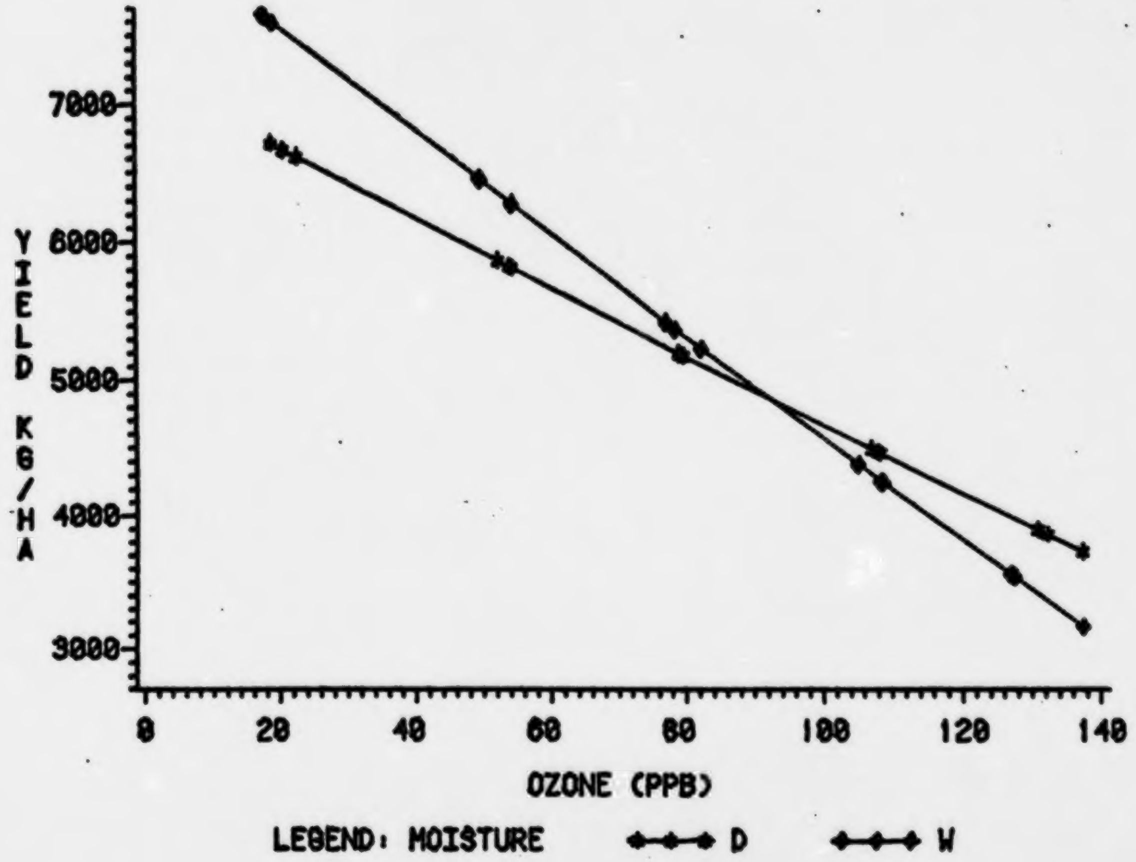


Figure 4.2.2.3. Predicted yield response to O_3 dose (7-hr seasonal mean) and to two moisture regimes for cultivar 'Williams'. (See Table 14 for regression equation.)

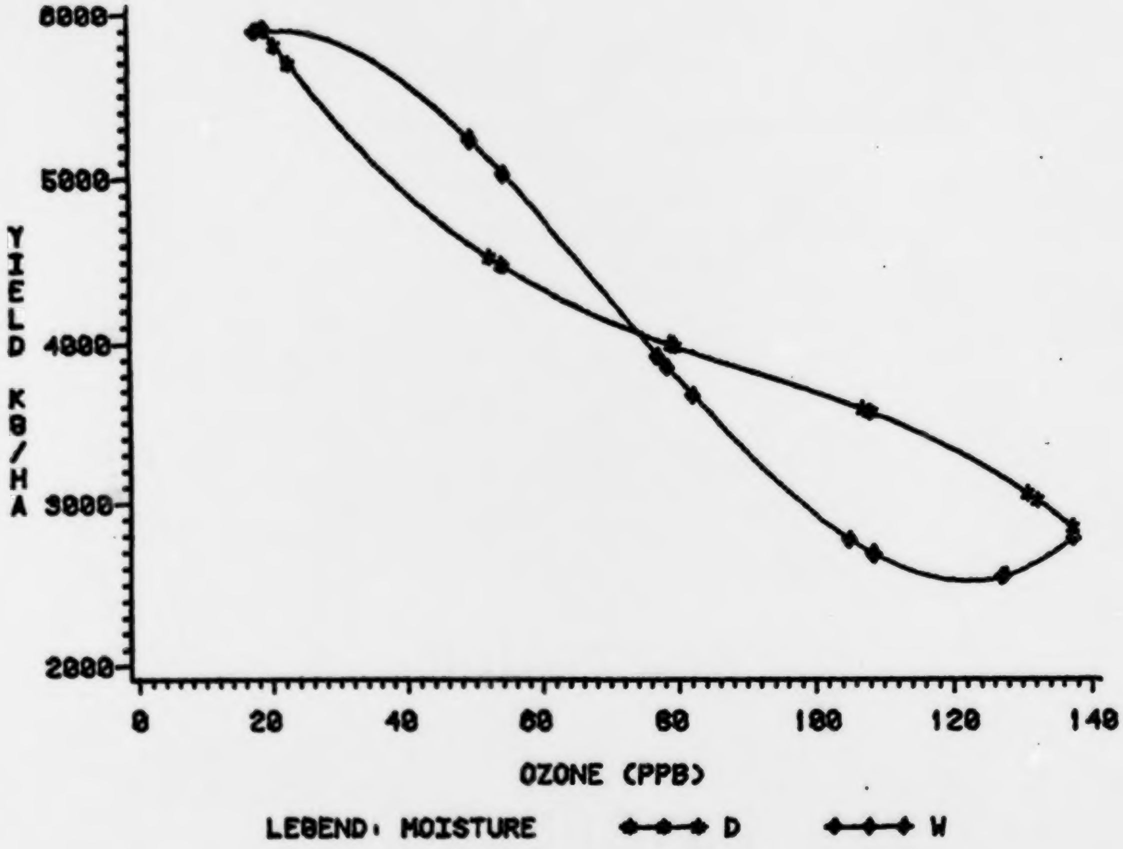


Figure 4.2.2.4. Predicted yield response as related to O_3 dose and moist and dry soil (soil water potentials) for cultivar 'Corsoy.' (See Table 14 for regression equation.)

Table 4.2.2.15. Weibull equations relating yield (kg/ha) to seasonal 7-h/day mean O_3 concentration (ppm).*

Cultivar	Soil Moisture	Model
Corsoy	Moist	$Y = 6332 \exp [-(x10.130)^{1.493}]$
	Dry	$Y = 7651 \exp [-(x10.158)^{0.615}]$
Williams	Moist	$Y = 7885 \exp [-(x10.146)^{1.586}]$
	Dry	$Y = 6521 \exp [-(x10.191)^{1.649}]$

*Table courtesy Dr. W. W. Cure, Department of Botany, North Carolina State University.

There is evidence from our field experiments in 1982 and 1983 that soybeans can acclimate to soil moisture stress if grown in charcoal-filtered air and the soil moisture stress develops slowly and is not too severe. This was especially true for the cultivar Corsoy in 1983. The yield decreases due to exposure to current levels of ambient O_3 may be greater than previous data would indicate.

The yield data from AA plots do not support the results from the NF chambers. That is, 'Corsoy' in AA plots showed about the same yield reduction in the moist and dry soil series using the CF chamber data for comparison. 'Williams' showed more yield reduction in moist soil than dry soil. It is of value to make comparisons between AA plots and the NF chamber plots when trying to interpret possible chamber effects. For example, to maintain the same soil water potential in the primary root zone in AA plots as in NF chamber plots, the AA plots had 62% of the water in the moist series and 79% of the water in the dry series (Table 4.2.2.3.). The AA plots produced only 77% of the yield in the moist series and 93% of the yield in the dry series. It is possible that evapotranspiration was greater in the chambers or that dew supplemented soil moisture in the AA plot. We can only speculate as to the reason for the difference in plant response. There are no reasons to believe soybean response to O_3 is changed significantly by the chambers.

4.2.2.5. Conclusion

The cultivar-O_3 dose-response functions were altered by soil moisture stress. Especially with 'Corsoy' the effects of O_3 in ambient air were greater under soil moisture stress conditions than when soil moisture stress was avoided. With both cultivars at the 0.06 and 0.09 ppm O_3 concentrations, there was evidence of some protection from O_3 injury by soil moisture stress. The data suggest that 'Corsoy' acclimated to soil moisture stress to a greater extent than 'Williams' when grown in charcoal-filtered air. The effects of the indicated levels of soil moisture stress on the yield response to O_3 were similar in 1982 and 1983.

4.2.3. Response of Winter-Season Barley to O_3, 1983 (SWCLAP)--P. Temple and O. C. Taylor

4.2.3.1. Introduction

Barley (*Hordeum vulgare* L) is one of the 10 most important crops in the United States, with a cash value of approximately $1 billion in 1979. Yet relatively little is known of the chronic effects of O_3 on growth and yield of barley, although it is listed as a susceptible species based on the occurrence of symptoms of foliar injury. A dose-response experiment was conducted in 1981-1982 using short-season cultivar 'Poco'. This cultivar was selected because it could be planted after cotton was harvested, and it would be mature enough to harvest before the spring planting of cotton. The results of this study indicated that this cultivar did not show loss in productivity when exposed to the relatively low concentration of O_3 present during the winter in the San Joaquin Valley of California. Because 'Poco' is not widely grown in California and because the growing season was unusually short in 1982, results of this experiment were considered to be preliminary, and the experiment was repeated in 1982-1983 using barley 'CM-72,' which is the major cultivar grown in the San Joaquin Valley of California.

Spring barley is grown almost exclusively under irrigation in the Central Valley. Timing of irrigations and amount of water applied can strongly affect plant responses to O_3. Plants grown under water stress may be more resistant to O_3 than those grown under irrigation conditions that maintain soil moisture at levels for optimum plant growth. Thus the objectives of this research were to 1) provide dose-response information on the effects of O_3 on productivity of field-grown barley as part of a regional and national assessment of the impact of O_3 on crop losses and 2) determine if dose-response curves of barley irrigated with optimum and sub-optimum water regimes responded differently to O_3.

4.2.3.2. Methods and materials

Crop Establishment and Irrigation. Fertilizer (21-10-0) was applied at a rate of 67 kg/ha and incorporated by rototilling on December 10, 1982 (Table 4.2.3.1). Barley cv. 'CM-72' was seeded in 6 rows spaced 15 cm apart at a rate of 60 kg/ha on December 14, 1982 onto beds spaced 100 cm apart. After germination, 30 separate 6 m x 6 m plots were created in the barley field by diking 10 plots in three strips oriented east-west. The diking permitted each plot to be furrow-irrigated independently. Neutron probe tubes were placed in each of three plots on the east and west ends of the field to a depth of 1 m and two irrometers were installed in sample areas of each plot at depths of 45 cm and 60 cm. Additional irrometers were installed 45 cm from each neutron probe tube at depths of 30 cm, 45 cm, and 60 cm for correlation of neutron probe and irrometer readings. Neutron probe readings were conducted weekly during the growing season by personnel of the California Irrigation Management Information Systems. Irrigation treatments were designed to return soil moisture to prescribed levels of field capacity. Allowable soil moisture depletion in the normal (optimal) irrigation plots were 70% of field capacity in the first 30 cm of soil depth, 50% in the next 30 cm, and 40% in the third 30 cm of depth. In water-stressed plots, these allowable depletions were 85%, 60%, and 60%, respectively. Allowable soil moisture depletion in sub-optimal plots were 20-25% greater than in normally-irrigated plots. Xylem pressure potentials were measured weekly on flag leaves of non-sampled plants in each of three normally-irrigated and water-stressed plots.

Ozone Treatments and Monitoring. Ozone treatments were randomly assigned to 28 plots and 24 open-top chambers were placed over plots on January 26, 1983, when plants were 15-20 cm tall and canopy 15% closed. The four additional plots served as chamberless (AA) controls. Companion plots were established in each plot by marking off an area 1 x 4 m on the bed 1 m south of each chamber or AA plot sample area. Blowers were operated by time clock and were set to operate from 30 min before sunrise to 30 min after sunset, daily. Ozone additions and pollutant monitoring began on February 3, when plants were 20-24 cm tall and at the four-leaf stage. Ozone additions were in proportion to ambient O_3 concentration measured in an AA plot and were 25%, 50%, 75%, and 100% of ambient. Ozone was added daily between 0900-1600 PST until May 8, whenever ambient O_3 exceeded 30 ppb. Two additional O_3 treatments were in charcoal-filtered (CF) and non-filtered (NF) chambers. The six O_3 treatments and AA plots were replicated four times. Ozone dispensing, monitoring, and data

Table 4.2.3.1. Chronology of significant events during study of the effects of O_3 on 'CM-72' barley, Shafter, CA, 1982-1983

1982	Nov. 11	Plots rototilled
	Dec. 10	Fertilizer applied and beds formed
	14	Barley seeded at 60 kg/ha
1983	Jan. 3	Plants emerged in uniform stand
	26	Chambers placed on plots
	31	Blowers started
	Feb. 3	Ozone additions & exposure monitoring initiated
	4	Irrometers installed
	10	Irrigation started
	18	Lodging problem first occurs
	Mar. 14	First irreversible lodging
	28	Anthesis becomes evident
	Apr. 8	Malathion sprayed for aphids
	13	Barley at soft dough stage
	26	Last irrigation
	May 8	Last day of O_3 addition
	23	Harvest
	Jun. 8-10	Samples threshed

acquisition systems were the same as those used in previous field experiments. All NCLAN quality assurance protocols regarding instrument calibration and line loss measurements were made at prescribed intervals.

Plant Growth and Development. The barley was uniform and asymptomatic except for scattered symptoms of chilling injury at the beginning of the exposure period. The chambers and plots were systematically examined for pests, diseases, injury symptoms, and plant development during the course of the exposure. Symptoms of common barley diseases were widespread but of low incidence, and were not related to O_3 or irrigation treatment. No O_3 injury symptoms were observed. Anthesis began on March 28. The grain was at the firm to hard dough stage and the plants largely senescent by May 8, when O_3 additions were terminated.

Bird feeding on grain was controlled by placing bird netting over all chambers and plots. Aphids on barley heads were controlled with a 0.05% solution of Malathion 50, sprayed over all plots on April 9, 1983.

Several severe winter wind and rain storms produced a series of lodging events throughout the season. Lodging was more severe in chambers than in AA plots, but was unrelated to O_3 or irrigation treatments. Degree of lodging was recorded for each chamber or plot.

Harvest Procedures and Data Analysis. Chambers, AA plots, and companion plots were harvested on May 23. A 4 m^2 area was marked off in the center of each chamber or plot, and four separate 1-m sub-samples of the south-central sample (seed) row were harvested from each quadrant in the chamber or plot. The remainder of the 4 m^2 sample area was cut and bulked. Companion plots were sampled as a 1 x 4 m section of the first bed south of each chamber or AA plot sample area. Head counts and weight per head were determined for subsamples. All samples were mechanically threshed and bulk seed weight and weight per 100 seeds determined at 10% moisture content. All samples were collected, stored, and weighed in accordance with NCLAN quality assurance protocols for the processing of biological samples.

Companion plots were examined for systematic variation across the field, but as no significant trends were observed, these data were not included in the final analyses. Yield data from bulk plots were extremely variable, due primarily to lodging in some chambers. No bulk data were obtained from two normally-irrigated and four water-stressed plots. Because of this variability, and because of lack of replication of some O_3 treatments, bulk yield data were not included in the final data analyses. Harvest data were analyzed by analysis of variance using a completely randomized split-plot design with O_3 and irrigation as main plot factors and position in chamber as the sub-plot factor. Dose-response relationships among O_3 and harvest parameters were analyzed by multiple regression analysis.

4.2.3.3. Results

Air Quality. Ozone concentrations were very low during the sampling period 3 February to 22 May 1983. Mean seasonal 7-h (0900-1600) ambient O_3 concentration during this period was 0.030 ppm. Ambient O_3 concentrations rose gradually during the course of the experiment (Figure

4.2.3.1). Mean seasonal 7-h O_3 concentrations for the six chamber treatments were, in ascending order: CF-0.015 ppm, NF-0.030 ppm, NF x 1.25-0.040 ppm, NF x 1.50-0.047 ppm, NF x 1.75-0.055 ppm, NF x 2.0-0.064 ppm. Mean seasonal diurnal curves for these treatments are shown in Figure 4.2.3.2. Other expressions of O_3 exposure including highest 1-h concentration, highest 7-h concentration, and seasonal mean of the daily 1-h maximum concentrations are given in Table 4.2.3.2.

Plant Responses. Total precipitation plus irrigation averaged 53.6 cm in optimally-irrigated plots and 34.0 cm in water-stressed plots, a 36% reduction (Table 4.2.3.3). Water-stressed plots had lower yields than those given normal irrigation (Table 4.2.3.4), and analysis of variance of harvest data indicated that these differences were statistically significant (Table 4.2.3.5). Seed yield in m-row samples was reduced 24% in water-stressed ambient air plots and 11% in water-stressed chamber plots compared to normally-irrigated treatments. Position within the chamber was also significant, but as position x O_3 and position x irrigation interactions were not significant, within chamber samples were pooled for regression analysis. Response to O_3 was not statistically significant, except for a significant quadratic response in weight per 100 seeds. However, regression analysis indicated no significant relationship between O_3 dose and response of barley yield (Figure 4.2.3.3). Exposure to O_3 as high as 0.064 ppm (seasonal 7-h mean) had no effect on yield either in normal or water-stressed plots.

4.3. INFLUENCE OF SO_2 ON O_3 DOSE-RESPONSE RELATIONSHIPS

4.3.1. Response of Winter Wheat to O_3 and SO_2 Exposure (NERCLAP)--

(Robert Kohut and Robert Amundson)

4.3.1.1. Introduction

The 1983 NCLAN field program at Boyce Thompson Institute was an integration of crop loss studies sponsored by the Environmental Protection Agency and the Electric Power Research Institute. The combined program resulted in an expansion of the facilities for plant exposure as well as the scope of the research.

The major thrust of the field research program was an evaluation of the effects of O_3 and SO_2, alone and in combination, on the growth, physiology, and yield of winter wheat. The winter wheat cultivar used was Vona, the same cultivar that was found to be highly O_3-sensitive in the 1982 dose-response study. To better understand the response of this cultivar to O_3 and SO_2, the dose-response studies were complemented with evaluations of plant growth and photosynthesis to provide an integrated assessment of treatment effects.

4.3.1.2. Materials and methods

Cultural practices. Winter wheat (*Triticum aestivum* cv. 'Vona') was planted with a drill on October 12, 1982, at a rate of 100 kg of seed per hectare in rows 17.5 cm apart and banded with 10-20-20 (NPK) fertilizer at a rate of approximately 280 kg/ha. Soils in the experimental plot are in the Collamer and Niagara series, both of which are Hapludalfs. The soils are described as silt loams. In May 1983 the field was top-dressed with

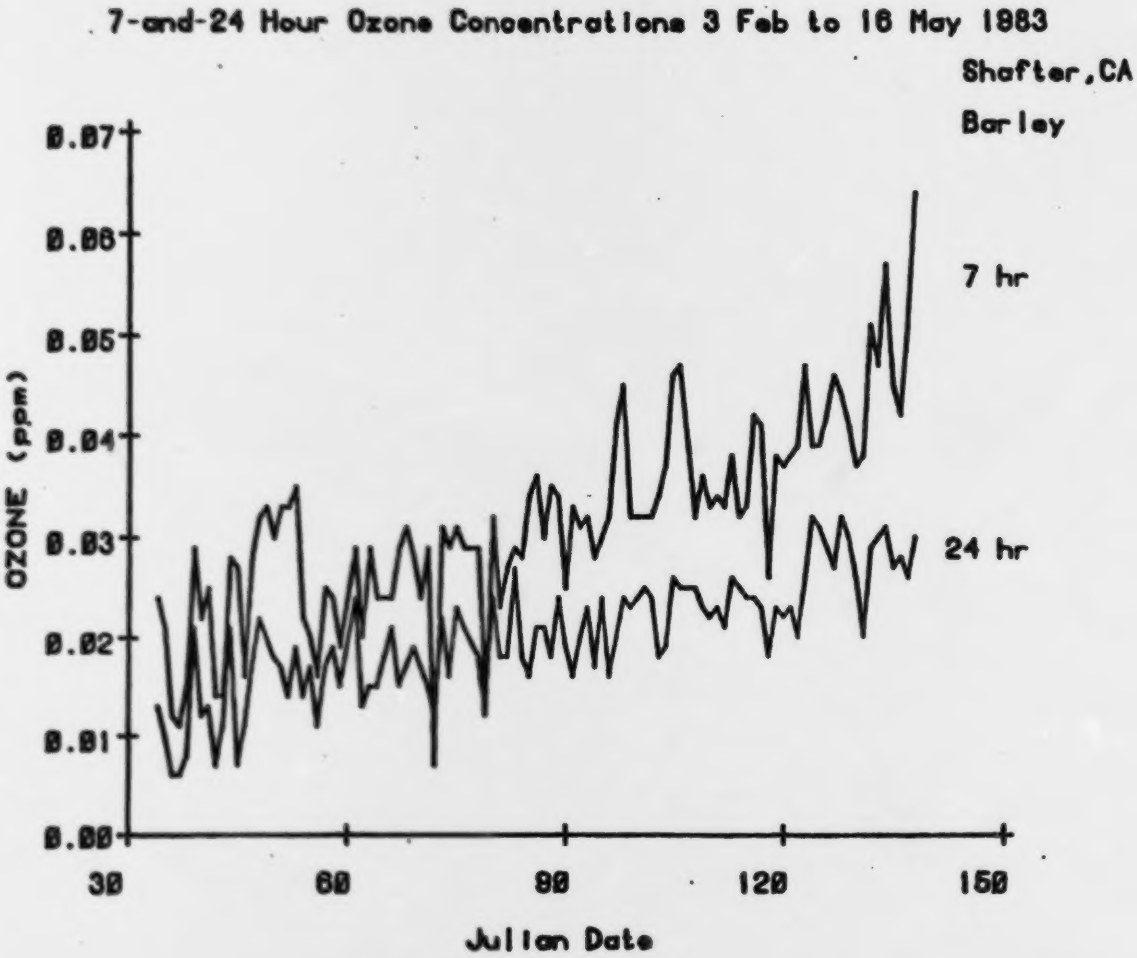


Figure 4.2.3.1. Daily 7- and 24-h mean ambient O_3 concentrations, 3 Feb to 16 May 1983 at Shafter, CA.

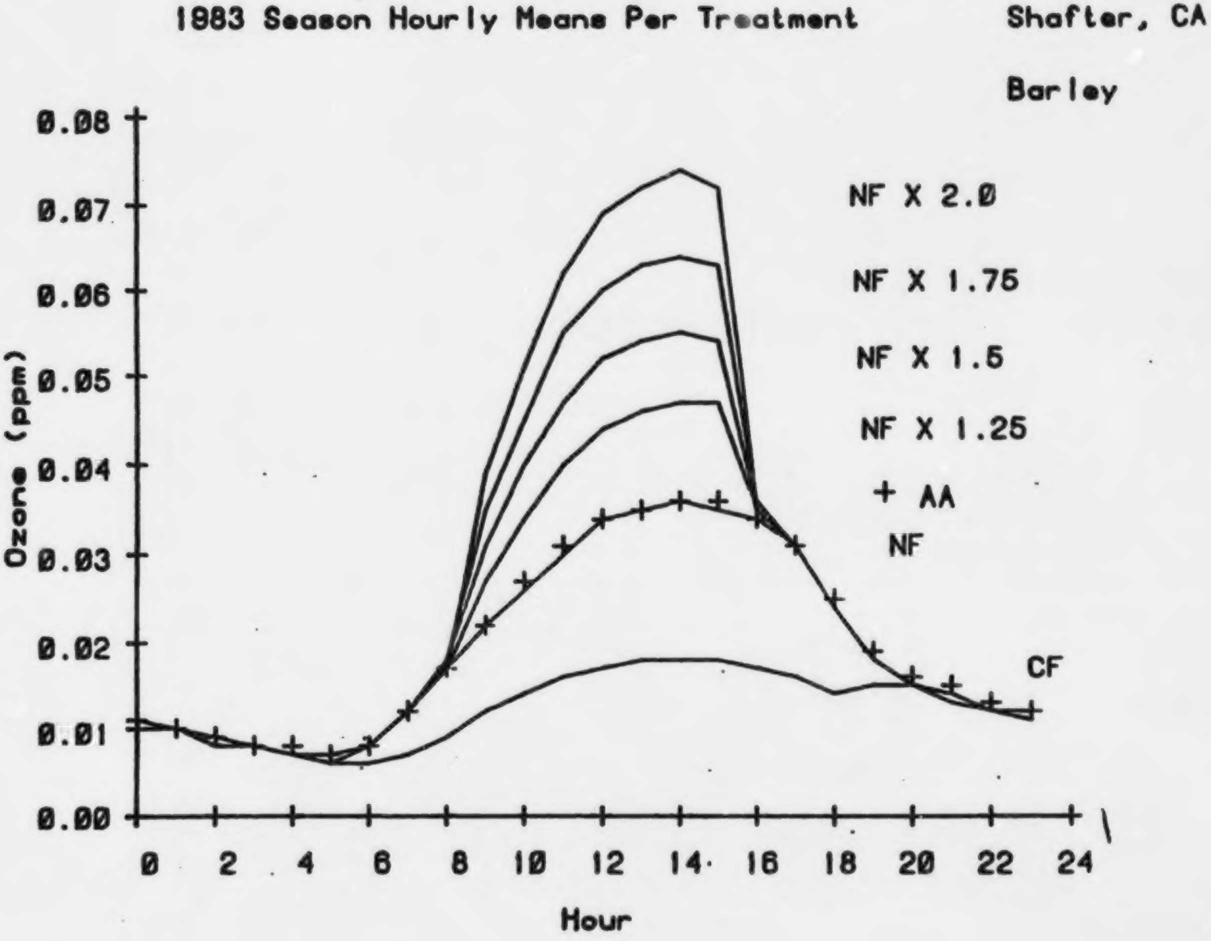


Figure 4.2.3.2. Diurnal curves of mean hourly O_3 concentrations for each barley treatment at Shafter, CA. 3 Feb to 8 May 1983.

Table 4.2.3.2. Summary of O_3 concentrations during exposure of barley, cv 'CM-72,' in open-top chambers at Shafter, CA, from 33 Feb to 8 May 1983

Treatment	7-h O_3 Means (0900-1600)-(ppm) Seasonal Mean	Maximum 7-h	1-h O_3 Means (ppm) Seasonal Mean	Maximum 1-h	Second Highest 1-h
CF	0.015	0.032	0.024	0.045	0.042
NF	0.030	0.049	0.036	0.059	0.055
NF X 1.25	0.040	0.071	0.050	0.091	0.086
NF X 1.50	0.047	0.088	0.059	0.114	0.104
NF X 1.75	0.055	0.103	0.070	0.132	0.126
NF X 2.00	0.064	0.116	0.082	0.149	0.140
AA	0.030	0.050	0.037	0.061	0.056

Table 4.2.3.3. Summary of significant precipitation and irrigation events during barley growing season, 1982-1983

Date	Amount (mm)	Date	Amount (mm)
A. Precipitation			
12-22-82	8.4	3-1	19.5
12-27	0.6	3-2	2.0
12-30	0.6	3-3	10.3
1-18-83	5.4	3-6	0.5
1-20	1.5	3-7	4.8
1-22	20.1	3-13	4.5
1-23	2.4	3-16	9.3
1-27	28.5	3-17	1.3
1-28	0.9	3-18	10.3
1-29	6.6	3-20	6.0
2-2	1.8	3-21	1.0
2-5	2.8	3-22	1.0
2-6	3.5	3-23	4.5
2-7	2.0	3-24	8.8
2-12	3.8	3-27	0.5
2-15	0.5	4-10	0.5
2-24	1.8	4-11	2.8
2-25	3.3	4-12	2.8
2-26	3.0	4-20	2.8
2-27	7.5	4-28	5.5
2-28	2.8	4-29	3.8
		4-30	3.8
		5-1	0.5

Table 4.2.3.3. Continued

Date	Amount (mm)	Date	Amount (mm)

B. Irrigations

	Amount (mm)	
Date	Normal Irrigation	Water Stressed
1-12-83	75	
2-22	43	
2-25		63
4-1	44	
4-4	25	50
4-14	50	
4-19		31
4-22	25	
4-26	50	

Table 4.2.3.4. Yield data for 'CM-72' barley exposed to O_3 in open-top chambers at Shafter, CA, 3 Feb to 8 May 1983

Treatment	M-row Samples**			Bulk Samples†	
	Wt/head (g)	Seed wt (g)	Wt/100 Seeds (g)	Seed wt (g)	Wt/100 Seeds (g)
I Normal irrigation					
CF	2.06	132	5.46	1409[c]	5.03
NF	2.22	117	5.16	1325	5.09
NF X 1.25	2.07	139	5.20	1301	4.92
NF X 1.50	1.85	129	5.00	1330[c]	5.10
NF X 1.75	2.00	131	5.14	1228	4.81
NF X 2.00	2.18	144	5.34	1183	4.90
AA	2.12	193	4.91	1283	4.50
II Water-stressed					
CF	1.84	134	4.91	1088	4.14
NF	1.79	113	4.84	1198	4.42
NF X 1.25	1.58	111	4.90	1181[c]	4.81[c]
NF X 1.50	1.63	118	4.56	-	-
NF X 1.75	1.66	118	4.79	1036[c]	4.77[c]
NF X 200	1.77	116	4.85	1081	4.52
AA	1.91	147	4.62	1324	4.44

* Means of two replicate chambers or AA plots.

**Average of 4, 1-m row samples from each chamber or AA plot.

†All plants in a 3.4 m^2 area centered in each chamber of AA plot.

[c] One replicate missing due to lodging in chamber.

Table 4.2.3.5. Analysis of variance mean squares for m-row harvest data of 'CM-72' barley exposed to O_3 in open-top chambers at Shafter, CA, 3 February - 22 May 1983

Source of Variation	d.f.	Wt/head	Seed wt.	Wt/100 Seeds
Ozone (O_3)	5	25.18	793.2	27.54
Linear	1	9.77	0.22	14.65
Quadratic	1	47.48	1175.6	76.81*
Residual	3	22.9	930.0	15.41
Irrigation (I)	1	306.74***	8797.5***	384.40***
O_3 x I	5	22.97	1618.1	3.98
Error a	12	15.57	826.4	11.19
Position (P)	3	271.96*	2069.0**	30.74*
P x O_3	15	33.56	385.9	1.99
P x I	3	29.40	146.2	9.20
P x O_3 X I	15	58.41	879.4	5.01
Error b	36	75.51	436.3	8.14

*Significant at 5%.

**Significant at 1%.

***Significant at 0.1%.

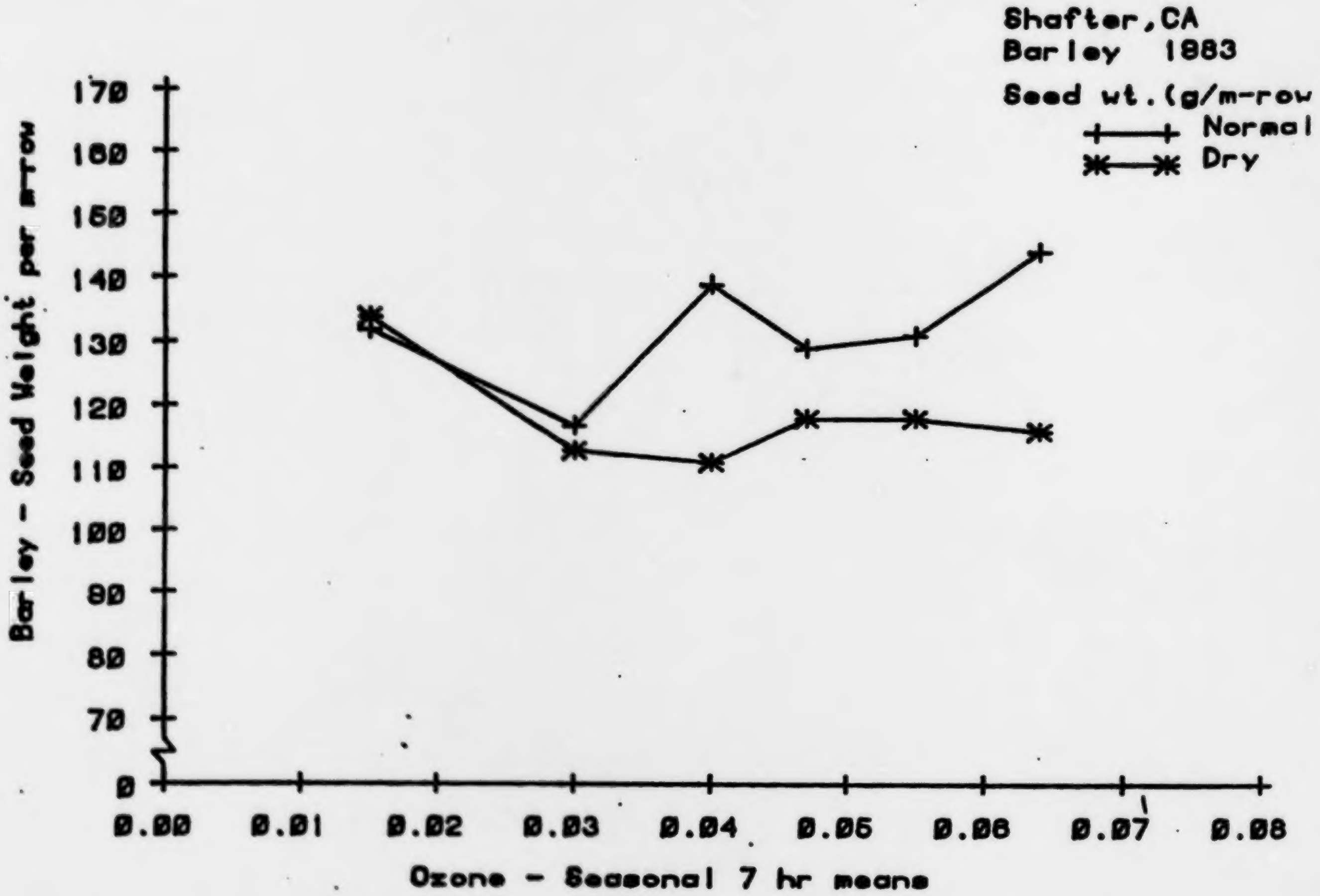


Figure 4.2.3.3. Treatment means for seed yield of barley grown under normal and sub-optimal irrigation and exposed to O_3 in open-top chambers at Shafter, CA, 3 Feb to 8 May 1983.

ammonium nitrate fertilizer at approximately 112 kg/ha. Stand density during the study was approximately 120-140 culms/m-row. Plants were sprayed with karathane on May 17 to control powdery mildew (Erysiphe graminis). Soil moisture at a depth of 25 cm was monitored with tensiometers to indicate the need for irrigation. It was decided that when 50% of the tensiometers had readings greater than 70, all chambers would be irrigated. There was no irrigation conducted during the study.

Pollutant Treatments and Monitoring. The four O_3 treatments in the open-top chambers were charcoal-filtered air (CF), nonfiltered air (NF), and nonfiltered air in which the O_3 levels were maintained at 1.4 and 1.8 times ambient by O_3 additions. A proportional controller directed by an ambient O_3 monitor was used to make the O_3 additions. Daily O_3 additions were 7 h in duration (1000 to 1700 EDT) except when precluded by rain or technical difficulties. The O_3 generation, distribution, and monitoring systems were similar to those used in previous NCLAN studies. Ozone monitoring was conducted with Monitor Labs Model 8410 instruments. Pollutant monitoring for each chamber was performed on a timesharing system where each observation was 2 min in duration and the chambers were sampled either two or three times each hour. The O_3 efficiency for each sampling line was determined twice during the study and taken into account during the reduction of the O_3 monitoring data. Ambient O_3 was monitored with a separate instrument. All O_3 monitors were subject to the NCLAN quality assurance program. Monitoring data were recorded with a Hewlett-Packard Model 85 computer with strip chart back-up.

There were four SO_2 treatments in the open-top chambers: nonfiltered air, and nonfiltered air to which 0.1, 0.3, and 0.6 ppm SO_2 was added. Exposures were 4 h in duration and conducted three times each week although variations in exposure duration and frequency occurred because of weather and equipment. The pollutant was produced with a tank of anhydrous SO_2 and metered into a manifold. Distribution into the chambers was regulated with flow meters. The SO_2 monitoring system was the same one used for O_3. The sample stream was split after passing through the sequencing valve and then entered the O_3 and SO_2 monitors. Trials of the split air stream system showed no influence of one instrument on the efficiency or functioning of the other. Monitoring was conducted with TECO Model 43 SO_2 monitors that were subject to the NCLAN quality assurance program. All SO_2 sample lines were teflon and had nearly 100% efficiency. As with O_3, monitoring data were recorded with a computer using strip chart back-up.

Treatments consisted of four levels of O_3, four levels of SO_2, and all combinations of the two pollutants at these levels for a total of 16 open-top chamber treatments. Four of the treatments, NF, NF + .3 ppm SO_2, 2 x ambient O_3, and 2 x ambient O_3 + .3 ppm SO_2 received two additional replications. Ambient plots not enclosed by chambers constituted another treatment. In May the winter wheat stand was evaluated for uniform plant density and soil condition and 48 treatment plots were selected. Treatments were randomly assigned to 24 plots in each of two blocks: 16 chamber treatments, 4 duplicated chamber treatments, and 4 ambient plots.

All chambers became operational between 1 June and 4 June. Ozone exposures were initiated on 12 June and terminated on 17 July. At the time exposure began, the heads on the plants were approximately three-fourths emerged. Flowering had not started. The SO_2 exposures were initiated on 22 June and terminated on 15 July. Flowering was completed and the kernels watery when the SO_2 exposures began. The delay in initiating treatments was due to the time required to of construct the chambers and blowers to conduct the SO_2 exposures. The kernels were fully ripe when the exposures were terminated and all chambers and plots harvested for yield on 18 and 19 July. The period for all exposure calculations in the study was 12 June through 17 July; a 36-day interval.

Physiology. Measurements of stomatal conductance of the flag leaves were started on 8 June and were made with a steady state porometer (LICOR, Model 1600, Lincoln NB). Four locally fabricated cylinders (cuvettes) were used to enclose approximately 25 cm of wheat row for measurement of whole plant net photosynthetic rates. The cylinder frame was made of clear plexiglass and was covered with transparent teflon (Type FEP, 1 ml). The cuvettes were aspirated by an impeller attached to a miniature electric motor. The top of the cylinder was perforated to allow entry of ambient air which was drawn out the bottom of the cylinder through teflon tubing to the CO_2 analyzer. Flow rates were maintained at 35 to 45 ℓ^{-1} to reduce heating or excessive reduction of CO_2 concentrations within the cuvette.

Measurements of whole-plant net photosynthesis were begun on 9 June and terminated on 7 July. In addition, two thermoelectrically cooled cuvettes (Portable Environment Cuvette, Kananaskis Centre for Environmental Research, Calgary, Alberta) were used to measure the net photosynthetic rate of individual heads of wheat; these measurements were started on 18 June and terminated on 11 July. Two infrared gas analyzers (Anarad Inc., Santa Barabara, CA) were used to monitor changes in CO_2 concentrations for determination of either whole plant or individual head net photosynthesis.

Growth. Measures of plant growth were made at approximately 1-week intervals from 6 June until final harvest. All plants in a 25-cm section of row were clipped at ground level and the number of culms (head bearing stems), tillers (non-headbearing stems), and emerged heads were counted. The dry weights of tillers, culms less the emerged heads, and heads were measured after drying at 75° C for 48 h. Eight chambers and four ambient plots remained unsampled during the course of the experiment with only the final yield of the two center rows taken. The yields from the unsampled chambers and plots were compared with those from the same treatments that were sampled to determine if sampling for the growth study affected yield.

Dose-Response. The dose-response analysis used the harvest data collected from the 16 treatments of O_3 and SO_2 alone and in combination. On 18 and 19 July, plants were harvested from two 1-meter rows in the center of the chamber. The plants were cut near the ground and the heads clipped from the straw. The heads and straw were oven-dried at 75° C for 48 h. In each chamber, 20 heads were individually threshed and the seeds weighed and counted. Regression analysis was used to evaluate the effects of the treatments on total yield and 100-seed weight.

4.3.1.3. Results

Pollutant Monitoring. The daily ambient 7- and 24-h average O_3 concentrations are presented in Figure 4.3.1.1. For O_3, the seasonal 7-h and 24-h average concentrations, the maximum and second maximum 1-h average concentrations, the seasonal average of the daily maximum 1-h concentrations, the maximum 7-h concentration, and the number of hourly averages above 0.08 and 0.12 ppm were determined for each chamber treatment and ambient air (Table 4.3.1.1). Ozone additions were made on 34 of the 36 days of the study period. Charcoal filtration reduced the O_3 concentration to approximately 50% of that in the ambient environment. The 7-h average concentrations showed comparable levels of O_3 in the AA and NF treatments while the levels in the O_3-added treatments (1.4x and 1.8x) were slightly below their target values (1.5x and 2.0x). The diurnal pattern of the average hourly O_3 concentrations for each chamber treatment and ambient is presented in Figure 4.3.1.2. The effect of the proportional controller is evident at the beginning of the daily exposure period with the elimination of the step-function previously seen. Termination of the exposure produced a rapid decrease in the concentration of O_3 in the pollutant-added treatments.

In the ambient treatment, the hourly average of 0.08 ppm O_3 was exceeded 55 times and 0.12 ppm was exceeded 5 times. These levels of ambient O_3 occurred more often in 1983 than in previous years. The O_3-added treatments had increasing numbers of hours above the two index levels with the 1.8x treatment having 182 h above 0.08 ppm and 76 h above 0.12 ppm.

The SO_2 exposure data were also evaluated to characterize the treatments (Table 4.3.1.2). Exposures were conducted on 12 days during the study with 9 of the exposure periods being 4 h in duration. Ambient SO_2 was extremely low with detectable levels (> 0.005 ppm) occurring on 50 h out of the 864 h in the study period. For both the ambient and nonfiltered SO_2 treatments, the fumigation period and 24-h concentrations were essentially zero. The fumigation period average concentrations in the SO_2-added treatments were somewhat below their respective target values, but produced distinct treatment levels. The exposures were relatively uniform with low peak:mean ratios. The secondary standard for SO_2 was not exceeded in any of the treatments. The diurnal pattern of SO_2 concentrations for the fumigation days and for all days during the study period are presented in Figure 4.3.1.3. The 24 days on which fumigations were not conducted during the 36-day study produced major reductions in the SO_2 treatment averages.

Compared to the long-term climatic averages for Ithaca, NY the 1983 growing season was characterized by slightly lower temperatures in April and May and average temperatures in June and July. Precipitation was below average for most of the growing season. Precipitation for May, June, and July was 14%, 23%, and 73%, respectively, below the long-term average. A compilation of precipitation events from June 1 through harvest is presented in Table 4.3.1.3.

Physiology. Stomatal conductances of flag leaves of plants exposed only to O_3 were measured before the start of the treatments and continued until the flag leaves were chlorotic. Ozone was found to have an immediate

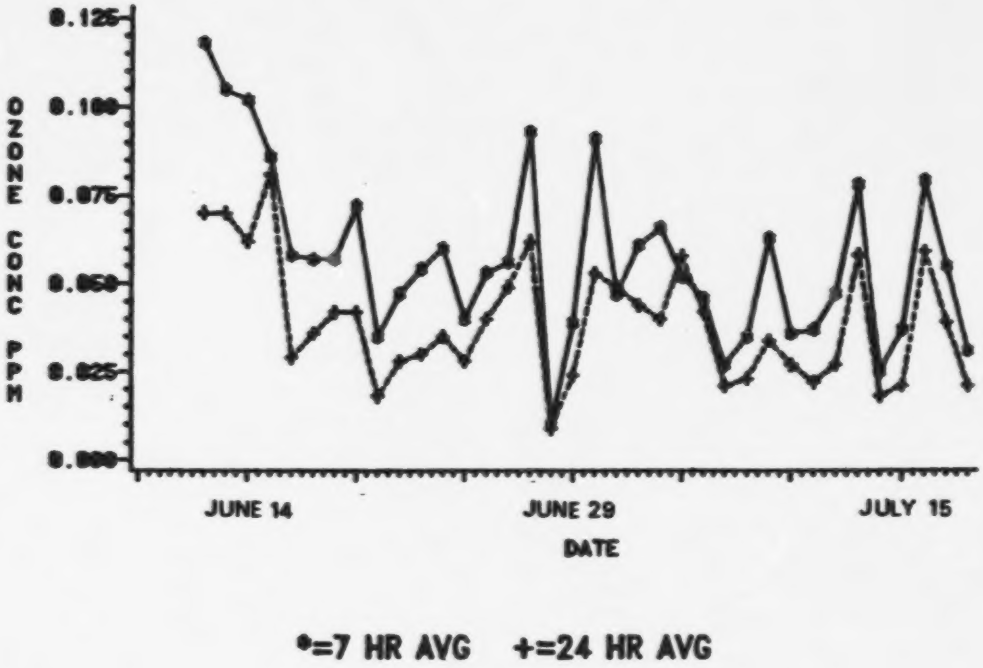


Figure 4.3.1.1. Daily ambient 7- and 24-hour average O_3 concentration during the exposure period in the 1983 winter wheat study in Ithaca, NY.

Table 4.3.1.1. Treatment-level characterizations of the O_3 exposure regimes in the 1983 winter wheat study at Ithaca, New York*

Treatment	7-h Average	24-h Average	Max 1-h	Second Max 1-h	Average Daily 1-h Max	Max 7-h	Second Max 7-h	Hours >.08	Hours >.12
CF	0.027	0.020	0.076	0.075	0.044	0.068	0.064	0	0
AA	0.057	0.038	0.128	0.127	0.069	0.118	0.105	55	5
NF	0.054	0.037	0.116	0.108	0.068	0.096	0.093	54	0
1.4x	0.076	0.044	0.153	0.147	0.093	0.150	0.124	122	23
1.8x	0.096	0.050	0.199	0.180	0.121	0.168	0.157	182	76

*All O_3 concentrations in ppm.

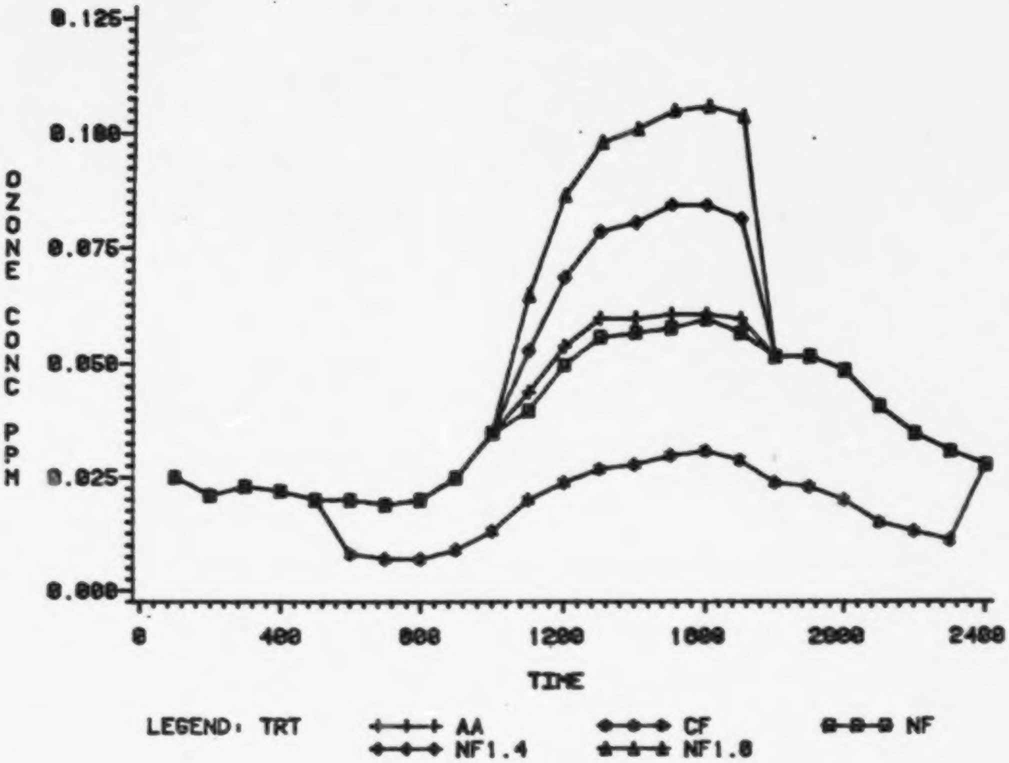


Figure 4.3.1.2. Diurnal pattern of the seasonal hourly O_3 concentrations in the 1983 winter wheat study in Ithaca, NY. Treatment designations are ambient air (AA), charcoal filtered air (CF), nonfiltered air (NF), 1.4x the nonfiltered concentration, (NF x 1.4), and 1.8x the nonfiltered concentration (NF x 1.8).

Table 4.3.1.2. Treatment-level characterizations of the SO_2 exposure regimes in the 1983 winter wheat study at Ithaca, New York*

Treatment	Exposure Days only					All days		
	Exposure Period Avg.	24-h Avg.	Max 1-h	Avg. Daily 1-h Max	Peak:Mean ratio	Exposure Period Avg	24-h Avg	Avg. Daily 1-h Max
Ambient	0	0	0.025	0	-	0	0	0
Nonfiltered	0	0	0.025	0	-	0	0	0
Nonfiltered + .10	0.039	0.007	0.069	0.051	1.3	0.013	0.002	0.018
Nonfiltered + .30	0.166	0.029	0.266	0.196	1.2	0.056	0.010	0.072
Nonfiltered + .60	0.363	0.63	0.509	0.428	1.2	0.121	0.021	0.154

*All SO_2 concentrations in ppm.

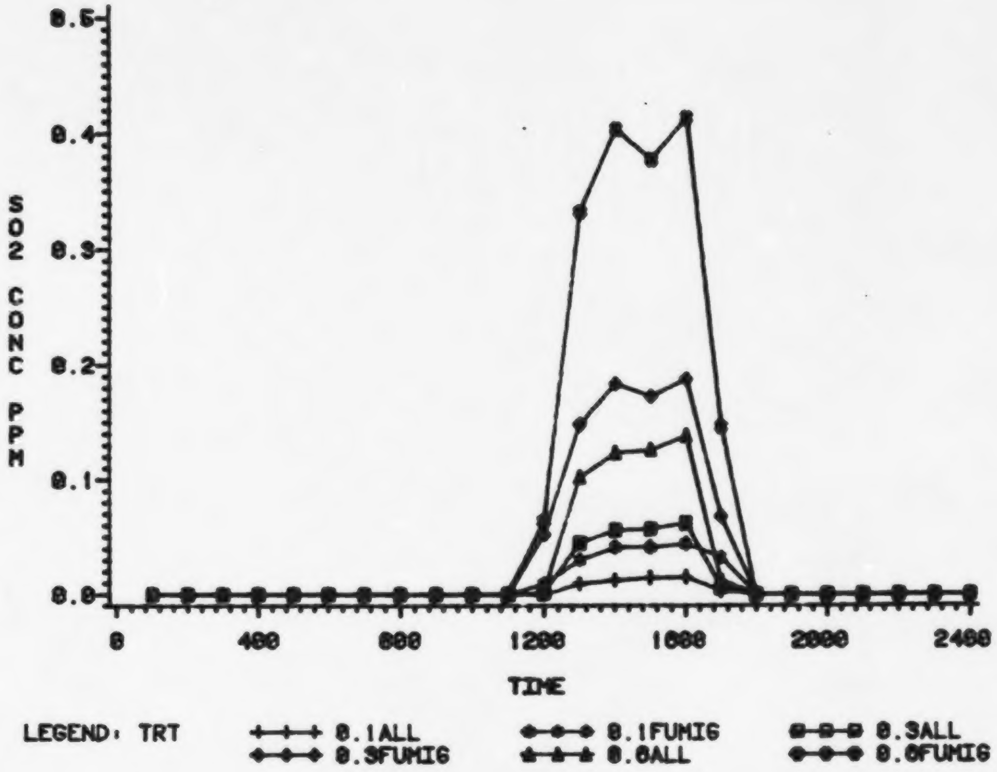


Figure 4.3.1.3. Diurnal pattern of the seasonal hourly SO_2 concentrations in the 1983 winter wheat study in Ithaca, NY. Hourly values are for the 0.10, 0.30, and 0.60 ppm SO_2 target-concentration treatments for all days (ALL) and fumigation days only (FUMIG).

Table 4.3.1.3. A compilation of daily precipitation during the 1983 winter wheat study in Ithaca, NY*

April		May		June		July	
Date	Precip.	Date	Precip.	Date	Precip.	Date	Precip.
3	0.61	1	0.41	1	0.51	2	T
4	0.03	2	0.46	2	T	5	T
8	0.91	3	0.05	4	0.18	6	T
9	T	4	0.41	6	0.08	9	0.18
10	0.99	6	0.05	7	1.04	16	0.30
11	0.41	8	T	17	0.23		
12	0.64	9	1.65	18	0.74		
15	1.32	15	0.05	19	0.46		
16	4.72	16	0.64	28	2.70		
17	0.03	19	0.38	29	1.78		
18	0.03	23	0.51				
19	0.03	24	0.15				
20	1.57	26	0.43				
21	2.08	27	T				
24	0.28	29	T				
25	2.41	30	0.03				
26	0.43	31	0.46				
29	T						

*Dates not listed in the table had no precipitation. All precipitation measurements are cm with T indicating trace.

inhibitory effect on both upper surface (Figure 4.3.1.4) and lower surface (Figure 4.3.1.5) stomatal conductance of the flag leaves. The differences in stomatal conductances among treatments remained essentially the same from the start of the O_3 exposures until the end of the measurement period. One exception was that the difference between the NF and CF treatments was larger during the last five days of measurements; a time when the flag leaves in the NF treatments were considerably more chlorotic than those in the CF treatments.

Stomatal conductances were also measured on flag leaves of plants exposed to all concentrations of O_3 with or without added SO_2. The average stomatal conductances of the upper and lower leaf surfaces of flag leaves monitored from the start of the SO_2 treatments until the leaves were chlorotic are shown in Figure 4.3.1.6. Exposure to SO_2 reduced stomatal conductance of both leaf surfaces in all O_3 treatments. The reductions ranged from 15 to 30 percent with no apparent interaction among the four O_3 treatments.

Net photosynthesis of whole plants was reduced by exposure to increasing concentrations of O_3 (Figure 4.3.1.7). The measurements were made over a period of 23 days from the start of the O_3 treatments until 10 days before the final harvests. The average net photosynthetic rate of plants exposed to the 1.8 x ambient O_3 treatment was 50% of the rate of plants exposed to the CF treatment (Figure 4.3.1.7). The dry weight per head of grain was also reduced by approximately 50% which was the percent decrease of average net photosynthesis over the period when the grains were being filled (Figure 4.3.1.7).

The net photosynthesis of individual heads of wheat was also monitored from 18 June until 6 July, 14 days before the final harvest. The average net photosynthetic rate of heads exposed to the 1.8 x ambient O_3 treatment was reduced by 50% when compared to the average rate of heads exposed to the CF treatment (Figure 4.3.1.8). This percentage reduction was approximately the same as that found for the whole plant net photosynthesis over a similar exposure period. In addition, the reduction in grain weight per head was essentially the same as the reduction in net photosynthesis per head (Fig. 4.3.1.8). Net photosynthetic rates of whole plants and individual heads of wheat exposed to all SO_2 concentrations were not significantly different from the rates of whole plants or heads exposed to comparable O_3 concentrations without SO_2.

. Growth. Destructive harvests from all treatments were made on six separate dates before the final harvest. The influences of O_3 and SO_2 on average head weights are shown in Figures 4.3.1.9 and 4.3.1.10, respectively. Exposure to the 1.8 x O_3 treatment reduced the average head weight by 50% compared to heads in the CF treatments (Figure 4.3.1.9). In contrast, no clear trend for effect of exposure to SO_2 on head weights was found (Figure 4.3.1.10). At all harvests the number and dry weight of head-bearing (culms) and non-head bearing (tillers) stalks per 25 cm of row were determined. Since the pollutant exposures were initiated at head emergence, no effects of the pollutants on head number per 25 cm row were found. In addition, since most of the vegetative portion of the plant had developed prior to the start of the exposures, no effects of treatments were found on total plant weight even though head weights were reduced by the O_3 treatments.

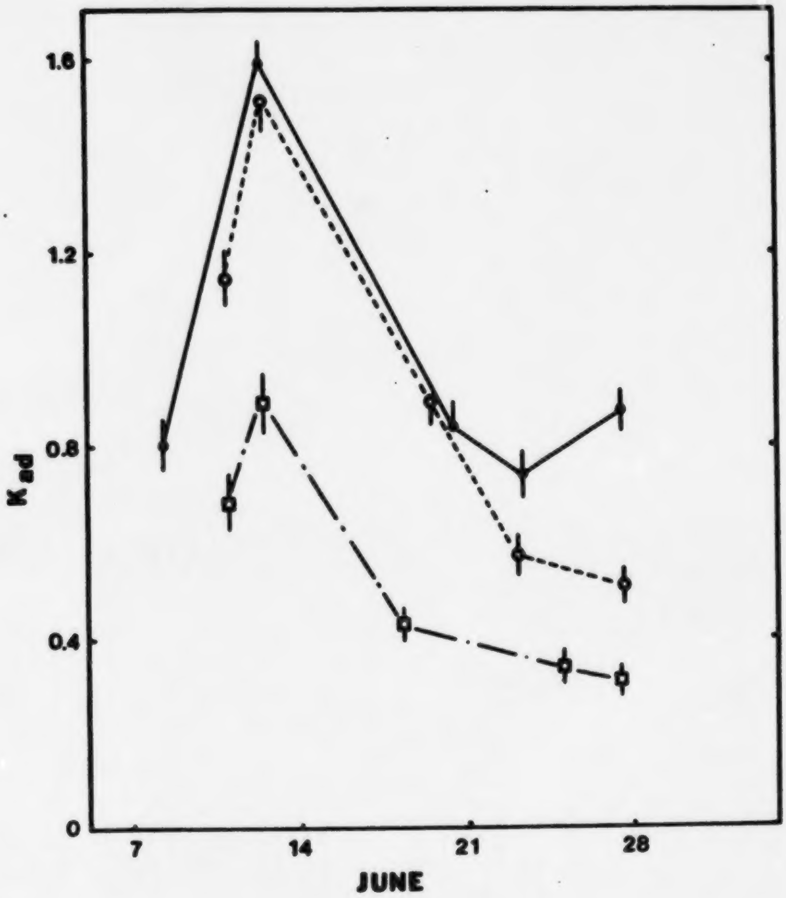


Figure 4.3.1.4. The effects of O_3 and time on stomatal conductance (cm s^{-1}) of the upper surface of the flag leaf (K_{ad}). Ozone treatments were: CF, ●-● ; NF, o-o ; and NF x 1.8, □-□ . The CF treatment started on June 3 and the O_3 additions began on June 12. Vertical lines indicate the ± standard error of the means.

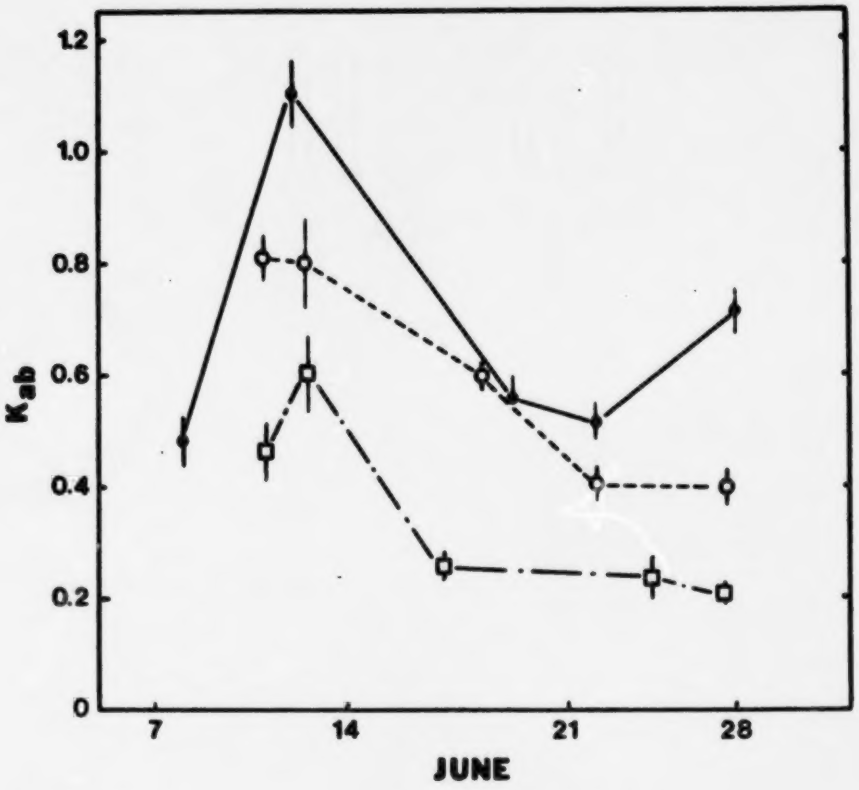


Figure 4.3.1.5. The effects of O_3 and time on stomatal conductance (cm s^{-1}) of the lower surface of the flag leaf (K_{ab}). Ozone treatments were: CF, ●-● ; NF, o-o ; and NF x 1.8, □-□ . The CF treatments started on June 3 and the additions began on June 12. Vertical lines indicate the ± standard error of the means.

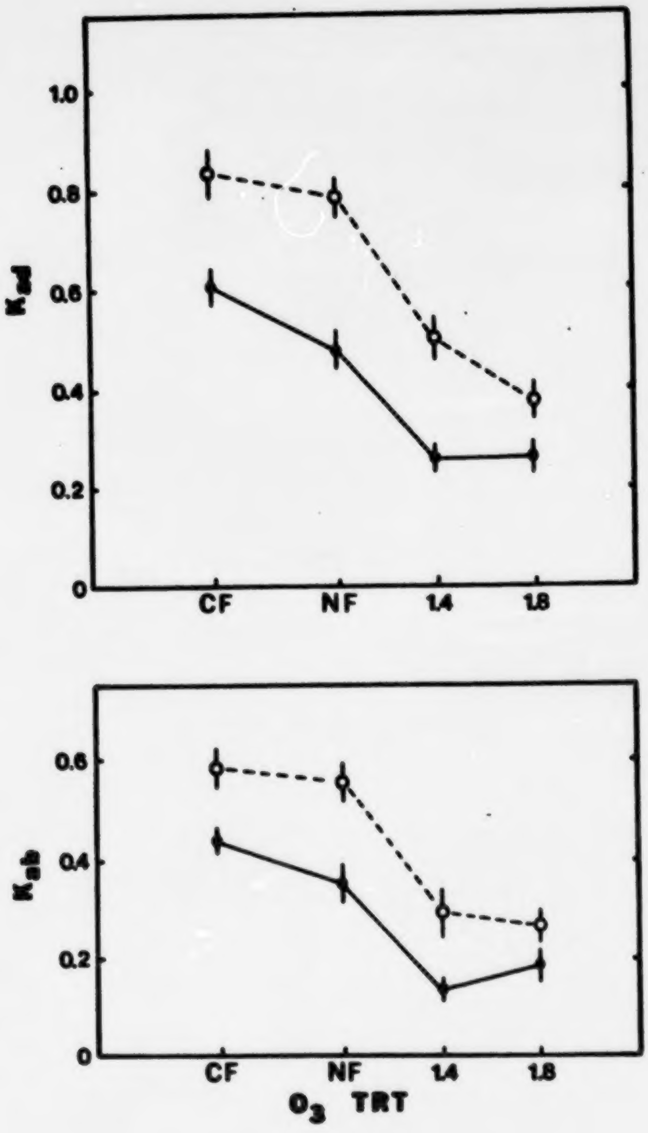


Figure 4.3.1.6. The effect of SO_2 exposure alone and in combination with O_3 on stomatal conductance (cm s^{-1}) of the upper (A) and lower (B) surface of the flag leaf. Open circles are for values from plants which were exposed to ambient SO_2; closed circles are for values from plants exposed to the high SO_2 treatment. Values were collected during afternoon exposures to SO_2 between June 20 and July 7. Vertical lines indicate the ± standard error of the means.

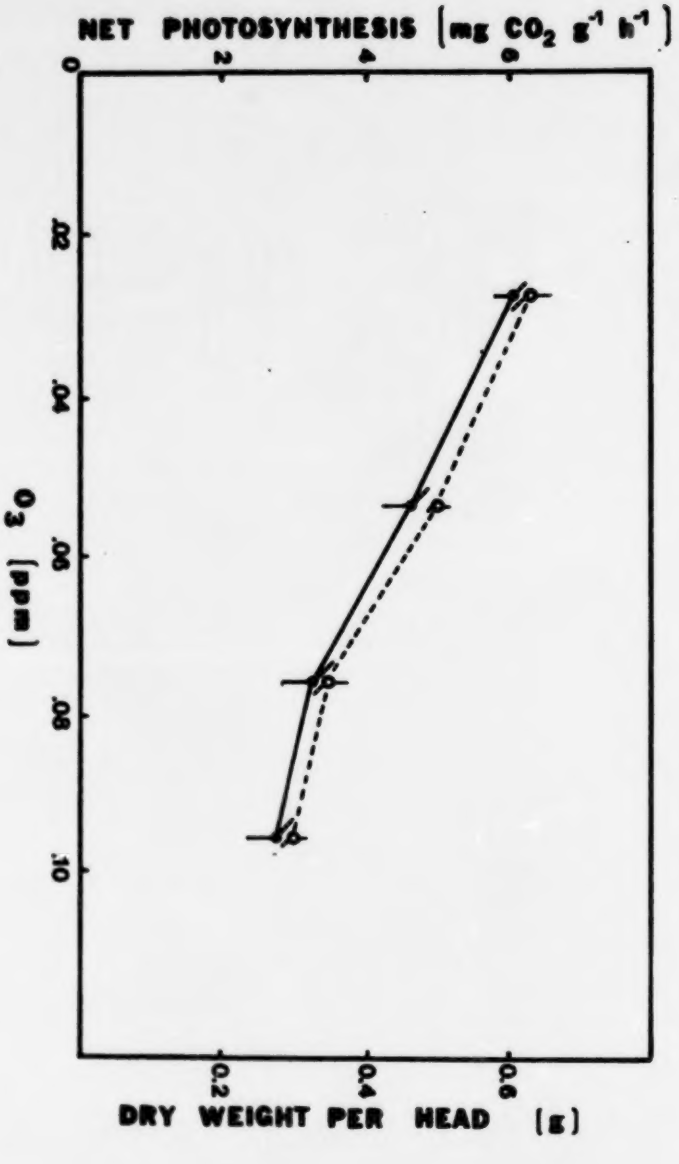


Figure 4.3.1.7. The effect of O_3 on whole plant net photosynthesis (●-●) and grain dry weight per head (o-o). Net photosynthesis values are expressed on the basis of mg CO_2 fixed per hour per gram dry weight of above-ground tissue less the weight of the seeds. Measurements of net photosynthesis were made between June 14 and July 1 and adjusted by covariate analysis for the effect of time.

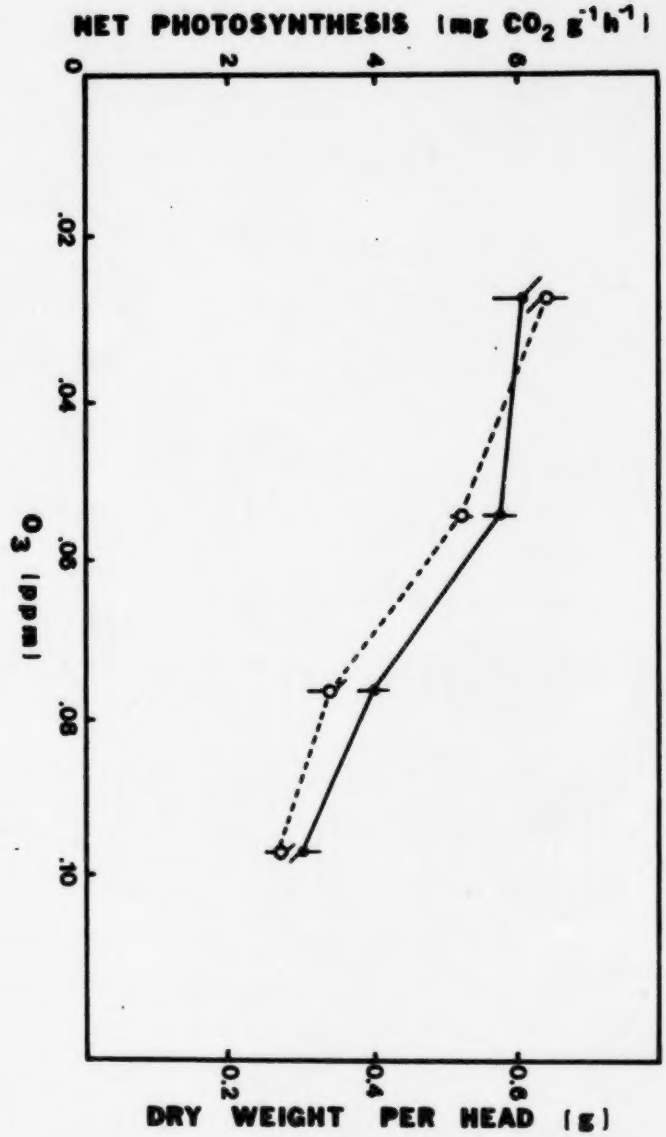


Figure 4.3.1.8. The effect of O_3 on net photosynthesis per wheat head (●-●) and grain per head (o-o). Net photosynthesis values are expressed on the basis of mg CO_2 fixed per hour per gram dry weight of the head less the weight of the grain and the rachis.

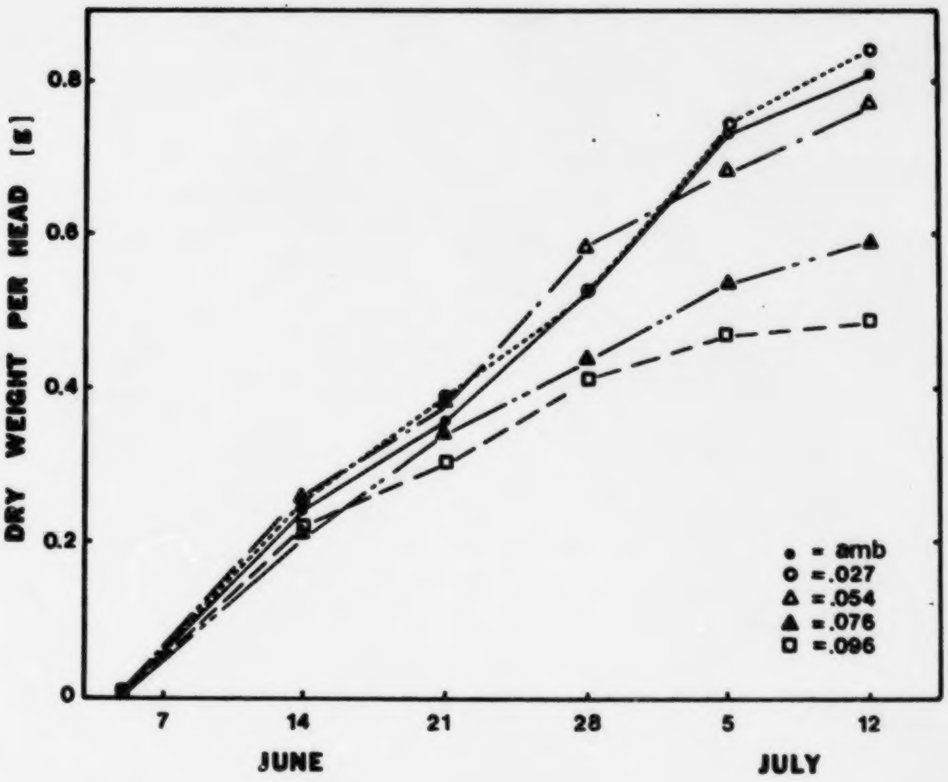


Figure 4.3.1.9. The effect of O_3 on the average weight per head of wheat. Values are averaged over all SO_2 treatments.

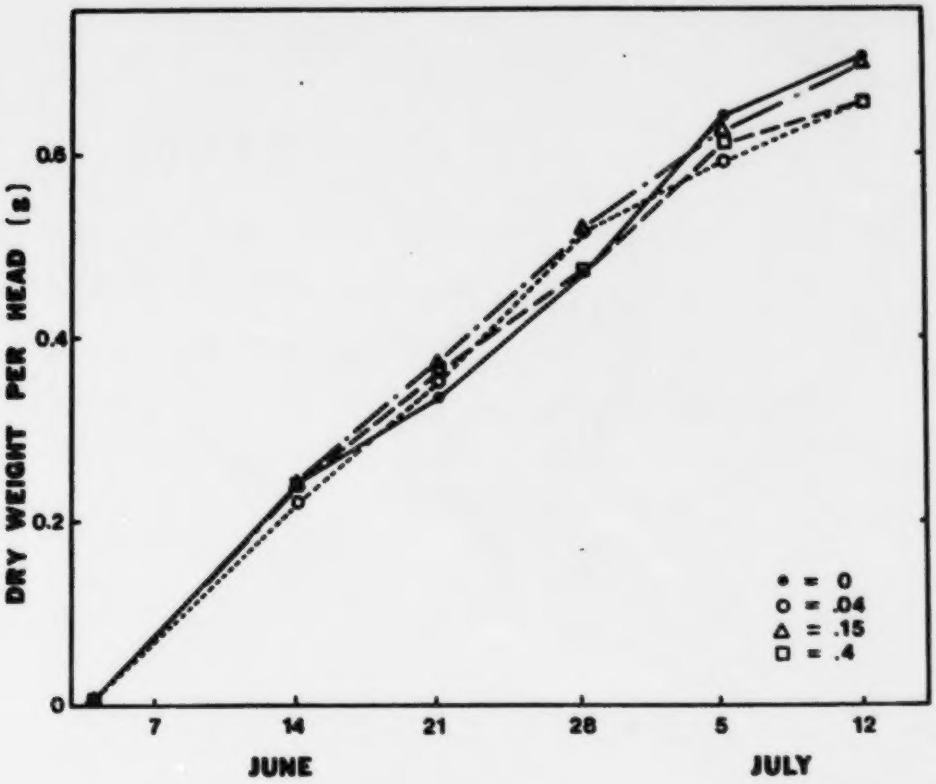


Figure 4.3.1.10. The effect of SO_2 on the average weight per head of wheat. Values are averaged over all O_3 treatmets.

Dose-Response. Harvest data from each chamber were tabulated and treatment-level yields calculated in kg of seed/ha (Table 4.3.1.4). Comparison of yields from chambers with and without growth harvests did not reveal any effects of these harvests on the final yield. Therefore, the yields from all chambers were used in the analysis. Trends in the treatment means indicate a reduction in yield due to O_3 and no effect of SO_2. Treatment means for 100-seed weights were calculated and are presented in Table 4.3.1.5. Trends in the data indicate an effect due to O_3 but none for SO_2.

Analysis of variance indicated that only O_3 had a significant effect on yield; the effects of SO_2 and O_3 X SO_2 were not significant (Table 4.3.1.6). A linear regression was conducted using the individual chamber 7-h O_3 treatment concentrations and yields in kg/ha. The regression equation obtained was: Yield = 5393.2 -31808 (O_3) where yield is kg/ha and O_3 is the seasonal 7-h average in ppm. A plot for the regression is presented in Figure 4.3.1.11. There was a high degree of variability in the chamber yield data which resulted in a relatively low R^2 value for the regression. The confidence bounds in the figure are the 95% confidence levels for the individual observations. Linear regression analysis was conducted for the 100-seed weight. The results of this analysis are in Figure 4.3.1.12. The regression curves for yield and 100-seed weight are nearly parallel indicating that the treatment effect was on seed size rather than seed number.

An analysis of yield response was also conducted using the Weibull model. Since the analysis of variance had indiciated that the SO_2 and O_3 by SO_2 treatment effects were not significant, the regression was conducted using only O_3 as a treatment. The response equation produced was: Yield = 4420.38 exp - $[O_3/0.109)^{2.735}]$ where yield is kg/ha and O_3 is the seasonal 7-h average in ppm.

4.3.1.4. Discussion

Ambient O_3 concentrations were higher in 1983 than in previous years. The ambient seasonal 7-h average was 0.057 ppm in contrast to averages of 0.043 ppm and 0.035 ppm in 1982 and 1981, respectively. The 55 hours of ambient O_3 concentrations above 0.08 ppm far exceeded the number of such observations in the past. In addition, the two hours of O_3 above 0.12 ppm comprise the first time that this level has been reached in the NCLAN ambient monitoring program at Ithaca.

Within one day after the O_3 exposures began, flag leaves on plants exposed to the 1.8x ambient treatment had significantly lower stomatal conductances than those in either the NF or CF treatments. Since the O_3 concentrations in the 1.8x treatments were approximately 0.2 ppm during the first week of exposures and plants in those treatments were visibly more chlorotic after the first week, the following factors most likely contributed to the reduced conductances: 1) increased internal CO_2 concentrations due to reduced net photosynthesis and/or increased respiration, 2) direct effects on stomatal metabolism, 3) damage to membranes of cells in the stomatal complex. Exposure to SO_2 was also found to reduce stomatal conductances. The similar reductions in stomatal conductances produced by the highest SO_2 concentrations at all O_3 concentrations indicated that the two pollutants acted independently.

Table 4.3.1.4. Treatment-level yields of grain (kg/ha) for the winter wheat cultivar 'Vona' grown in Ithaca, NY in 1983

Sulfur Dioxide (4-h ave, ppm)	Ozone (7-h ave, ppm)				Mean
	0.027	0.057	0.076	0.096	
0	4893	3834	2789	2041	3389
0.039	3411	4359	3569	2500	3460
0.166	4559	3872	2036	2089	3139
0.363	4577	3464	2879	2582	3379
Mean	4360	3882	2818	2303	

Table 4.3.1.5. Treatment-level 100-seed weights (g) for the winter wheat cultivar 'Vona' grown in Ithaca, NY in 1983

Sulfur Dioxide (4-h ave, ppm)	Ozone (7-h ave, ppm)				
	0.027	0.057	0.076	0.096	Mean
0	2.142	1.942	1.407	1.233	1.681
0.039	2.015	2.310	1.731	1.193	1.812
0.166	2.175	1.591	1.208	1.277	1.638
0.363	2.371	1.581	1.519	1.385	1.714
Mean	2.176	1.931	1.466	1.272	

Table 4.3.1.6. Analysis of variance for the yield data from the winter wheat study conducted in Ithaca, NY in 1983

Source of Variation	df	Sum of Squares	Mean Square	F	
Block	1	8070.5	8070.5	0.02	NS
O_3	3	23400789.6	7800263.2	18.29	**
SO_2	3	246285.2	82095.1	0.19	NS
O_3 X SO_2	9	6476453.8	719605.9	1.69	NS
Error	15	6395611.2	426374.1		

NS - Not significant

** Pr (value > F critical) = 0.01

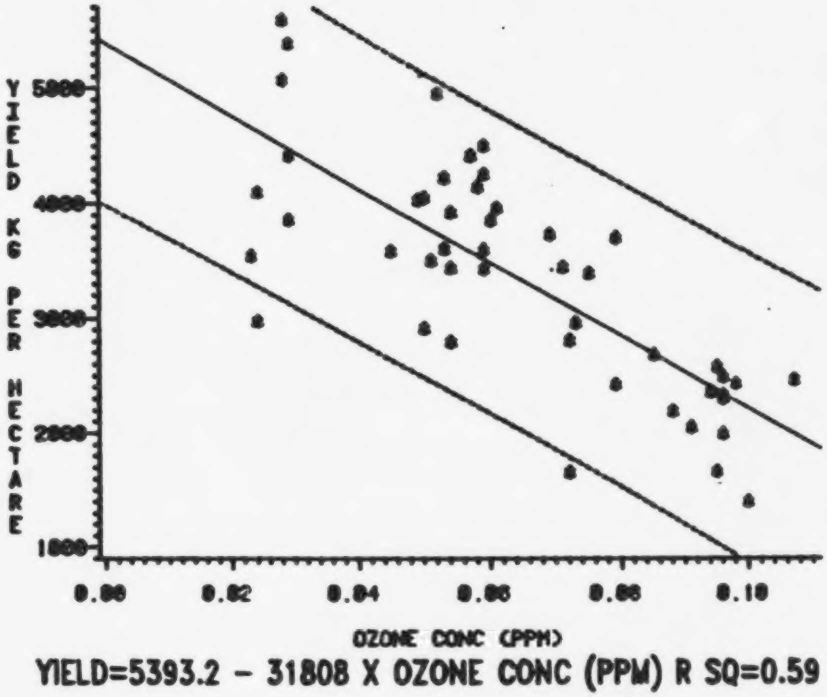
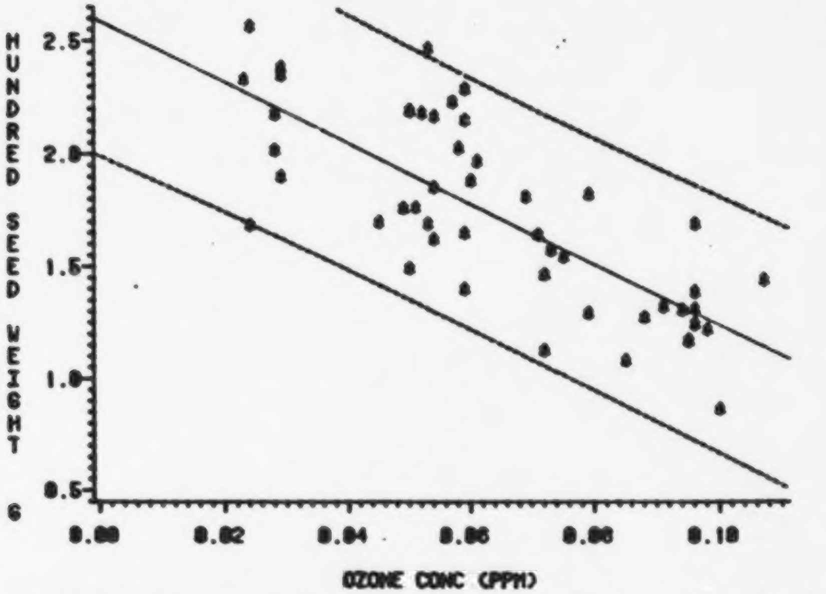


Figure 4.3.1.11. Yield data from open-top chambers and regression (with 95% confidence limits for individual observations) for O_3 effects on wheat yield in Ithaca, NY in 1983.



HUNDRED SEED WEIGHT=2.5886-13.522 X OZONE CONC (PPM)
R SQ=0.59

Figure 4.3.1.12. Data from open-top chambers and regression (with 95% confidence limits for individual observations) for O_3 effects on 100-seed weight in Ithaca, NY in 1983.

The general pattern of declining rates of net photosynthesis of whole plants with time from approximately one week prior to anthesis until senescence found in this study was similar to that found by Puckeridge (1971) and Johnson et al. (1981) for other winter wheat cultivars. The linear reduction in net photosynthesis produced by increasing concentrations of O_3 is in agreement with the results of studies on soybean (Reich et al. 1985) and hybrid poplar (Reich 1983). Of greatest interest was the fact that the percent reductions in net photosynthesis of both whole plants and individual heads corresponded to the percent reductions in yields of plants in the respective treatments. This suggests that during the period just prior to anthesis until senescence, any reductions in net photosynthesis caused by O_3 or perhaps any other stress will result in reduced yields. Since the number of heads was already set before the O_3 treatments began, there was no effect of O_3 on head number or plant size. However, the weight of the heads was reduced as a result of reduced seed weights.

Sulfur dioxide, both alone and in combination with O_3, had no effect on yield. The SO_2 exposures were initiated after flowering and provided the opportunity to affect only seed and not fill seed set. Although the SO_2 exposure period was relatively short, the absence of a yield reduction is consistent with the limited information available in the scientific literature (Sij et al. 1974, Swain and Johnson, 1936). The highest SO_2 treatment level, 12 4-h exposures at an average of 0.363 ppm, represents a series of exposures that is greater than the maximum exposure expected to occur in the vicinity of a scrubber-equipped coal-fired power plant.

In 1983, the O_3-induced yield reductions on the winter wheat cultivar 'Vona' were less than those produced in 1982. The concave response curve in 1982 had a Weibull distribution C coefficient of 0.853 while in 1983 the response was slightly convex with a C coefficient of 2.735 (Figure 4.3.1.13). Similarly, the best regression for the 1982 data was a quadratic function while a linear function fit the 1983 data. The change in the shape of the O_3 dose-response curve is not readily explainable although two factors may have been involved. The exposure period in 1983 was shorter than that in 1982 due to the expansion of the program facilities. Although the O_3 exposures were initiated before heading was completed and continued through grain maturation, the earlier vegetative period of growth occurred in the absence of charcoal-filtration or the O_3 additions. In addition, there was less precipitation in the 1983 growing season than in 1982. The difference in precipitation is probably an important factor in the reduction in yield in the charcoal-filtered treatment from 5331 kg/ha in 1982 to 4360 kg/ha in 1983 with similar O_3 concentrations for both years.

The dose-response curve from the 1983 study is similar to those produced for wheat in 1982 NCLAN studies (Kress et al., 1983a) at the Argonne National Laboratory (Figure 4.3.1.13). The cultivar 'Vona', however, is more sensitive to O_3 than are the cultivars 'Abe', 'Arthur-71', and 'Roland'.

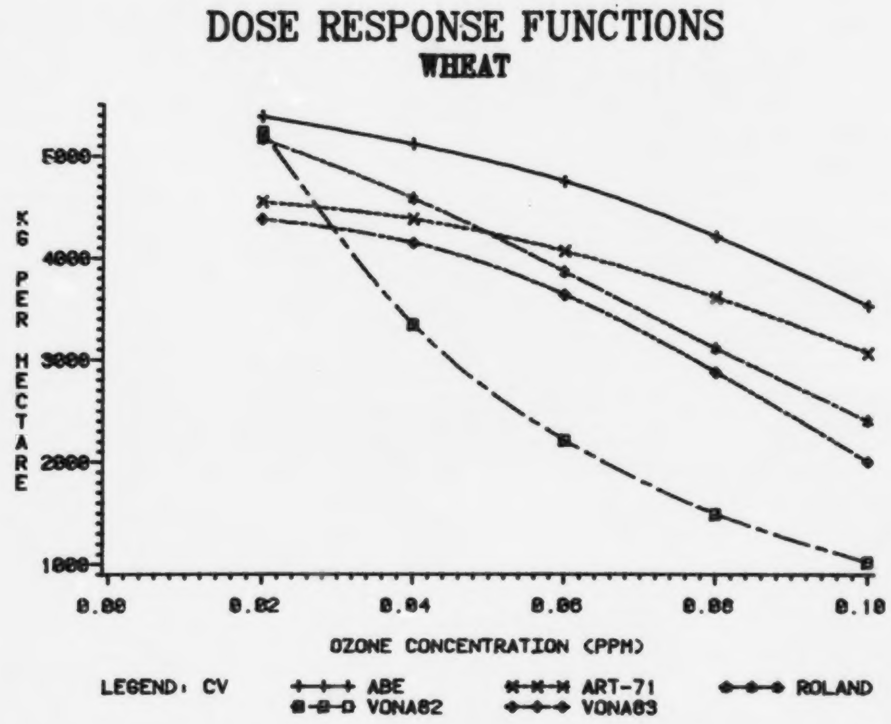


Figure 4.3.1.13. Dose-response curves for the effects of O_3 on the yield of winter wheat for three cultivars ('Abe', 'Arthur-71', and 'Roland'), evaluated in studies at Argonne National Laboratory in 1982 and 'Vona' used in studies at Ithaca, NY in 1982 and 1983. The curves were produced using the Weibull function.

4.3.2. Impact of O_3 and SO_2 on Winter Wheat (CSRCLAP)--Lance W. Kress and Joseph E. Miller

4.3.2.1. Introduction

This study was to be similar to the NERCLAP study on wheat (4.3.1) except that two midwestern cultivars were to be used. Performance of this experiment required the expansion of our physical facilities for pollutant exposure. Due to the late receipt of funding from EPRI, our equipment could not be put on line until the wheat plants had already headed and were flowering. We had altered our planned experimental design and had already begun a 6 O_3 x 3 replication dose-response study (4.1.2). A revised O3 by SO_2 experiment had the objective of determining the effects of intermittent SO_2 exposures on the yield of plants grown in charcoal-filtered or nonfiltered air.

4.3.2.2. Results

All plots were exposed to ambient air until mid-June. The plants were exposed to charcoal-filtered air or nonfiltered air for only 3 weeks and to the 4-h/day, 3-day/week SO_2 treatments (0.0 ppm, 0.1 ppm, 0.3 ppm, 0.6 ppm) for only 2 weeks.

No differences were noted in overall seed yield, 100-seed weight, or seed weight/head as a result of either the O_3 or the SO_2 treatments. No conclusions can be drawn from this study because the plants had developed so far before the treatments were begun.

4.3.3. Impact of O_3 and SO_2 on Soybean Yield (CSRCLAP)--Lance W. Kress and Joseph E. Miller

4.3.3.1. Introduction

Soybeans (Glycine max L.) are a major crop worldwide, and one of the leading cash crops in the midwestern U.S. They are sensitive to O_3 and reductions in yield have been demonstrated under simulated ambient field conditions (Kress and Miller, 1983; Heck et al., 1983b). They are also sensitive to elevated SO_2 concentrations that can occur near a point source (Sprugel et al., 1980).

The effects of O_3 and SO_2 on yield have been examined in some recent field studies. Additive yield reductions were noted for 'Dare' soybeans exposed to 0.10 ppm O_3 + 0.10 ppm for 6-hr/day for 133 days in closed-top field chambers; although SO_2 alone had no effect (Heagle et al., 1974). Mixtures of SO_2 and O_3 dispensed with a linear gradient field exposure system caused decreased yield of 'Hark' soybeans, but the possible interactive effects were not tested (Reich et al., 1982). Sulfur dioxide caused more yield loss of snap beans in open-top chambers with nonfiltered air than in chambers with charcoal-filtered air, indicating a synergistic effect of SO_2 and ambient O_3 (Heggestad and Bennett, 1981).

There has been only one study with seasonal exposures in field chambers designed to evaluate the dose-response relationship between yield and both O_3 and SO_2 (Heagle et al., 1983). That study found that a 7-hr/day seasonal mean O_3 concentration of 0.055 ppm could cause a 20%

yield reduction for 'Davis' soybean. Sulfur dioxide caused no effect except at concentrations above those known to exist regionally (> 0.026 ppm 4-hr/day seasonal mean). Neither pollutant altered the dose-response relationships for the other except at high concentrations where the effects were less than additive.

This study was initiated to evaluate the effects of daily O_3 and periodic SO_2 exposures on the yield of two soybean cultivars. The exposure regime was designed to simulate SO_2 exposures from a point source superimposed on a regional O_3 stress.

4.3.3.2. Materials and methods

Many of the important events regarding the experiment have been listed in Table 4.3.3.1. Seeds of two soybean cultivars (*Glycine max* (L.) Merr., 'Amsoy-71' and 'Corsoy-79') were hand-sown two seeds every 3.8 cm in 2-m rows, 76 cm apart on 13 July, 1983. The east row of each plot was 'Corsoy-79' and the west row was 'Amsoy-71.' A border row was planted 76 cm on either side of the experimental rows using pooled seed of the two cultivars.

The soil has been described previously (see Section 4.1.3.2). However, this portion of the field had not been used experimentally before. It had a pH of 6.9 ± .5 and 51,500 ± 13,000 kg/ha organic matter. The area had been fertilized in preparation for field corn (Table 4.3.3.1). Due to a prolonged dry spell in late July and early August, all plots were watered twice in August by hand at the rate of 7 liters per meter row (∿ 2.54 cm irrigation). The night following the second watering (16 August) there was 3.8 cm of rainfall. In general, the weather was hotter and drier than normal in July and August, and wetter than normal in September. Total rainfall from July - 18 October was 35.6 cm (about normal).

The experiment consisted of a four O_3 by four SO_2 treatment unreplicated design with two ambient air (AA) plots. The O_3 treatments were:

CF, charcoal-filtered air chamber;

NF, nonfiltered air chamber with a small amount of O_3 added to provide a concentration approximating that in the AA plot; and NF + 0.03 and NF + 0.06, nonfiltered air chamber with O_3 added from 0900-1600 CST daily to provide 0.03 and 0.06 ppm above ambient, respectively.

The four SO_2 treatments were: 0.0 ppm, 0.1 ppm, 0.3 ppm, and 0.6 ppm added from 1000-1400 CST three times per week. The open-top chambers were established over the plots on 26-27 July, and the fans operated from 0530-2130 CST. Ozone additions began on 28 July and SO_2 additions began on 1 August. Ozone and SO_2 additions were terminated 10-14 October as the leaves and pods in the plots became at least 90% chlorotic.

Methods for O_3 dispensing and monitoring were as described in the 1982 NCLAN annual report. Each plot was sampled for 2 minutes out of every 20 minutes. Sample line losses were 8-10%. Ozone was not dispensed on two full and seven half days due to rain.

Table 4.3.3.1. Dates for important events during the 1983 studies to determine the effects of O_3 on the yield of two soybean cultivars at Argonne, IL

Month	Day	Event
June	14	Fertilized plots in preparation for planting field corn - 229 kg/ha N, 163 kg/ha P, 163 kg/ha K (corn crop failed and these plots were then used for soybean)
July	1	11.4 cm rain
	3	0.53 cm rain
	11	Independent instrument audit
	13	Planted 'Corsoy-79' and 'Amsoy-71' soybean
	17	Calibrated sample lines @ 0.20 ppm O_3
	18	0.23 cm rain
	19	1.27 cm rain
	21	Soybeans emerging. Random sample line calibration checks (0.58 cm rain)
	26-27	Panels and fans on
	27	Thinned plots to 1 plant every 3.8 cm
	28	Began O_3 dispensing. Plants in early first trifoliolate stage - 10 cm tall
	29	0.13 cm rain
	30	0.10 cm rain
August	1	Began SO_2 dispensing
	8	Watered all plots - 7 liters per meter row (≅ 2.54 cm irrigation)
	10	0.76 cm rain
	16	Watered all plots - 7 liters per meter row (≅ .54 cm irrigation) - (3.81 cm rain)
	18	Flowering initiated
	19	Adjusted sample line inlet height
	25	Rain - no PM dispensing - O_3 (0.56 cm rain)
	26	Rain - no PM dispensing - O_3 and SO_2 (0.61 cm rain)
	27	0.08 cm rain
September	1	Adjusted sample line inlet height
	3	Random sample line calibration checks
	5	2.44 cm rain
	6	Rain - no AM dispensing - O_3 (0.13 cm rain)
	10	0.53 cm rain
	12	Replaced particle filters on fans
	15	Rain - no PM dispensing - O_3 (1.07 cm rain)
	16	0.05 cm rain
	17	1.83 cm rain
	18	3.56 cm rain
	19	Rain - no AM dispensing - O_3 (0.46 cm rain)
	20	Rain - no dispensing - O_3 (1.68 cm rain)
	22	Fans allowed to run all night to prevent frost damage (no frost occurred on any plots)

Table 4.3.3.1. Continued

Month	Day	Event
September	29	Foliar injury, pod count, and plant height evaluations
October	5	SO_2 dispensing equipment malfuction - dispense SO_2 on 6 October instead
	8	Rain - no AM dispensing - O_3 - (0.51 cm rain)
	10	Last SO_2 dispensing for all but 3 plots - (CF + 0.1, CF + 0.3, NF + .3)
	11	1.75 cm rain
	12	Rain - no AM dispensing - O_3. No SO_2 (0.51 cm rain)
	13	Last O_3 dispensing for all but 4 plots - (CF + 0.1, CF + 0.3, NF + 0.0, NF + 0.3) (0.23 cm rain)
	14	Last O_3 and SO_2 dispensing
	17-26	Harvested soybean pods as leaves abscised and pods turned brown
	19	0.08 cm rain
	20	1.52 cm rain
	23	4.72 cm rain
	27	Removed panels from chambers. First frost.
November	1-2	Sample line calibration checks @ 0.20 ppm O_3
	29	Soil samples collected from each plot

Methods for SO_2 dispensing and monitoring were similar to those for O_3, as described in the 1982 NCLAN annual report, except that SO_2 was measured with Meloy SA285E Flame Photometric analyzers. Sample line losses were essentially zero; SO_2 was not dispensed on one half day (1.5-h) due to rain.

Foliar injury (percent stipple, chlorosis, and necrosis) was estimated for all leaves of two plants/cultivar in all plots on 29 September. Overall chlorosis and percent defoliation were estimated for all plants on 13 October to determine senescence.

Pods from two 1-meter row sections of each cultivar were harvested from each plot on 17-26 October. Seeds were hand threshed, cleaned, counted, oven dried to < 1% moisture content (to assure that sample differences were not confounded by differing moisture content), and weighed. Measurements taken at harvest were number of plants, number of pods (with at least one seed), number of unfilled pods, and plant height. Seed weight/m row was adjusted to reflect 14% moisture content and converted to Kg/ha. The weight of 100 seeds (100 swt) was calculated for each plot by dividing the seed weight/m by the number of seeds and multiplying by 100. Soil samples collected after harvest were sent to the Soil and Plant Analysis Laboratory, University of Wisconsin, for analysis of pH, organic matter, P, and K.

A split-plot analysis of variance of the yield data gave the usual factorial partitioning of the sum of squares among the treatment combinations (O_3,SO_2,cultivar). However, since there was no true replication, direct estimates of the split-plot experimental errors were not provided by this analysis. The three factor interaction (O_3 x SO_2 x cultivar) was used as the estimate of Error b, the subplot error. To check on the presence of multiplicative interaction effects, the above analysis was repeated using the logarithmic transformed yield values; the residual mean square, from the O_3 x SO_2 interaction, after fitting a full bivariate quadratic model was used as the estimate of Error a. A bivariate Weibull model was developed for each cultivar and the combined cultivars assuming multiplicative impacts of O_3 and SO_2.

4.3.3.3. Results and discussion

Pollutant concentrations. The mean seasonal O_3 concentrations (7-h/day mean) from 28 July to 18 October for the AA, CF, NF, NF + 0.03, and NF + 0.06 treatments were 0.047 ppm, 0.023 ppm, 0.046 ppm, 0.066 ppm, 0.092 ppm, respectively (Table 4.3.3.2). The seasonal mean of the daily 1-h peaks was about 25% higher than the 7-h mean in each treatment except the CF, which was about 35% higher. Seven-h/day and 1-h/day high and second high values are also shown (Table 4.3.3.2). The CF chambers were effective in excluding an average of 50% of the ambient O_3. The NAAQS for O_3 of 0.12 ppm for 1 hour was violated in all treatments except the CF.

The daily 7-h and 24-h mean ambient O_3 concentrations between 16 July and 31 October 1983 have been presented previously (see Figure 4.1.3.1). The highest 7-h mean was 0.104 ppm on 18 August and the highest 24-h mean was 0.067 ppm on 28 July. The mean seasonal diurnal fluctuations

Table 4.3.3.2. Highest and second highest hourly (between 0900 - 1600 CST) and 7-h mean O_3 values, the seasonal daily peak mean, and the seasonal 7-h mean for each treatment, 28 July - 18 October, 1983, at Argonne, IL. For SO_2 the concentrations are 4-h/day mean values or 1-h/day peak values taken from the 3 days/week that exposures were performed

	7-h/day Values (ppm)			1-h/day Peak Values (ppm)		
O_3 Treatment*	Seasonal Mean	Highest	Second Highest	Seasonal Mean	Highest	Second Highest
AA	0.047	0.092	0.090	0.060	0.147	0.139
CF	0.023	0.062	0.055	0.031	0.073	0.071
NF	0.046	0.088	0.086	0.059	0.138	0.126
NF + 0.03	0.066	0.112	0.111	0.082	0.162	0.153
NF + 0.06	0.092	0.148	0.144	0.114	0.204	0.189

	4-h/day Values (ppm)			1-h/day Peak Values (ppm)		
SO_2 Treatment**	Seasonal Mean	Highest	Second Highest	Seasonal Mean	Highest	Second Highest
CF	0.017	0.051	0.039	0.024	0.072	0.056
NF	0.021	0.050	0.048	0.028	0.066	0.065
0.1	0.089	0.117	0.108	0.107	0.135	0.132
0.3	0.295	0.410	0.362	0.340	0.440	0.433
0.6†	0.564	0.728	0.671	0.629	0.777	0.760

*Each value is the average of twelve 2-minute samples per hour.

**SO_2 exposures were 4-h/day, 3-d/week. Total of 32 exposures.

†Total of 31 exposures.

in hourly O_3 concentrations for all treatments are shown in Figure 4.3.3.1.

The mean seasonal SO_2 concentrations (4-h/day, 3 days/week) in the CF, NF, 0.1, 0.3, and 0.6 treatments were 0.017 ppm, 0.021 ppm, 0.089 ppm, 0.295 ppm, and 0.564 ppm, respectively (Table 4.3.3.2). The ratio of the 1-h daily peak seasonal mean to the 4-h seasonal mean decreased rather uniformly from 1.4 in the CF plot to 1.1 in the 0.6 plot. The CF chambers excluded 15-20% of the ambient SO_2.

Ambient SO_2 was detected (detection limit = 0.005 ppm) during 33% of the hours between 28 July and 18 October, 1983. The highest 24-h mean, 3-h mean, 1-h mean, and instantaneous peak values were 0.020 ppm, 0.110 ppm, 0.145 ppm, and 0.185 ppm, respectively. The seasonal mean values were 0.005 ppm (24-h), 0.021 ppm (3-h peak), and 0.030 ppm (1-h peak). Sixty-three percent of the 1-h peak values occurred during the 7-h 03 addition period, and 68% of the 3-h peak mean values occurred at least partly during the 7-h O_3 addition period.

Foliar injury. Some injury was noted on the plants in the NF + 0.03 and NF + 0.06 treatments, but the injury was not as prominent as it was on a companion soybean study (see Table 4.3.3.3). The plants in this study did not appear to be as healthy as in the other study, although plant height and seed yields were very similar. It may be that the added SO_2 stress (which did appear to induce some injury) may have reduced the overall sensitivity in terms of foliar injury expression. Senescence was obviously enhanced by the O_3 treatments but not by the SO_2 treatments, although senescence was progressing more rapidly in this study than in the companion soybean study (Section 4.1.3). The plant height data showed a trend toward height reduction at the highest O_3 or SO_2 treatments.

Yield. Analysis of variance of the chambered plot data indicated significant O_3, SO_2, cultivar, and O_3 x SO_2 interaction effects on yield (kg/ha). There were no significant O_3 x cultivar or SO_2 cultivar effects. The analysis of variance with the log transformed yield values and partitioning the O_3 x SO_2 sum of squares through the linear and quadratic models indicated no significant multiplicative interaction between O_3 and SO_2. The overall yield effect (kg/ha or seed weight/plant) of O_3 averaged across all SO_2 treatments was nearly the same for both soybean cultivars (Table 4.3.3.4). The cultivar effect noted in the split-plot analysis of variance was due to greater yield for 'Amsoy-71' at all O_3 treatment levels. The individual seed weight was reduced more for 'Corsoy-79' than for 'Amsoy-71', but seed number was reduced more for 'Amsoy-71' than for 'Corsoy-79'.

The overall yield effect of SO_2 averaged across all O_3 treatment levels was similar for both cultivars (Table 4.3.3.5). The majority of the yield reduction appeared to be due to reductions in seed number rather than seed weight.

The Weibull regression equations for O_3 (Fig. 4.3.3.2) and for SO_2 (Fig. 4.3.3.3) obtained from the bivariate Weibull equation show the effects of the pollutants on overall yield for each cultivar. The Weibull regression equation is given as:

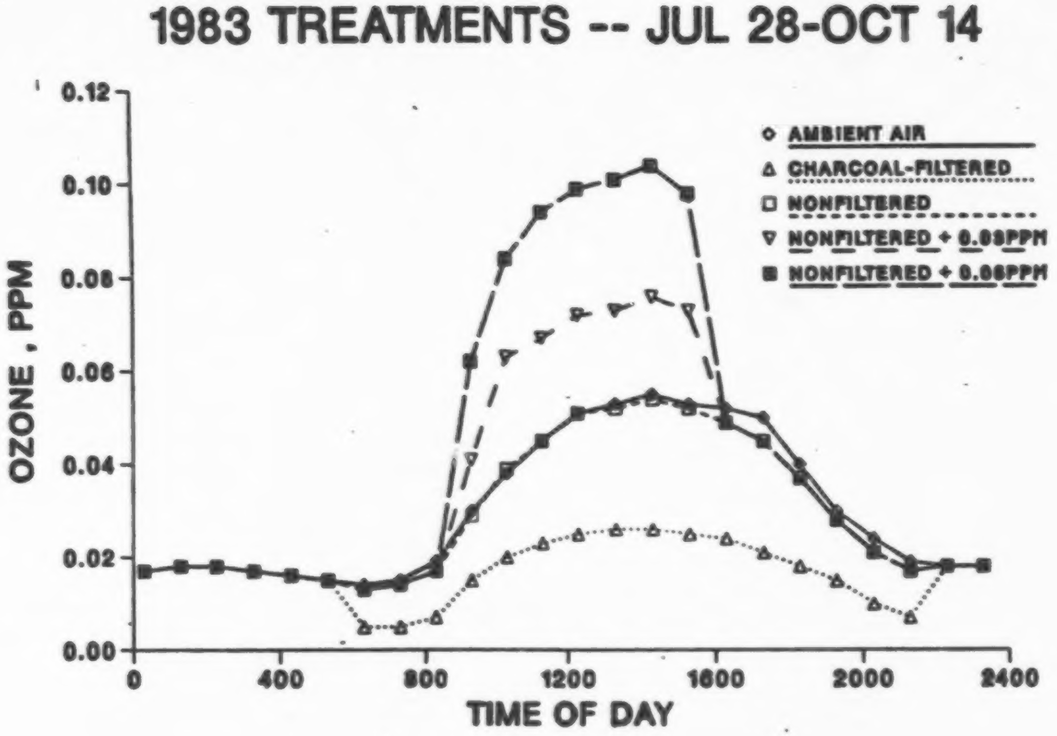


Figure 4.3.3.1. Mean seasonal hourly average diurnal fluctuations in O_3 concentrations for all treatments from 28 July - 14 October 1983

Table 4.3.3.3. Plant height, mean percent foliar injury, and mean percent senescence for soybean plants exposed to O_3 and SO_2 for 79 days at Argonne, IL, in 1983

Treatments[†]		Height (cm)	Injury* (%)	Senescence** (%)	Height (cm)	Injury* (%)	Senescence** (%)
	AA	48	1	35	42	6	75
	CF	42	1	50	33	8	80
O_3	NF	45	2	66	36	7	94
	+ 0.03	42	6	89	36	13	98
	+ 0.06	39	16	100	33	18	100
	0	43	2	68	36	4	90
	0.1	44	3	81	37	15	92
SO_2	0.3	43	8	68	34	13	94
	0.6	37	14	89	31	14	95

*Pigmented and chlorotic stipple and interveinal chlorosis on the most severely injured leaf of 1 plant/m row - average of 2 plants on 29 September 1983.

**Subjective estimate of the total percentage of chlorotic or abscised leaves per cultivar per plot on 13 October 1983.

[†] O_3 Treatments averaged across all SO_2 treatments

SO_2 Treatments averaged across all O_3 treatments

Table 4.3.3.4. Effects of O_3 on the yield of two soybean cultivars exposed for 7-h/day in open-top chambers for 79 days*

O_3 (ppm)	Amsoy-71				Corsoy-79			
	kg/ha	# seeds	100 swt**	sw/p†	kg/ha	# seeds	100 swt**	sw/p†
0.047 (AA)††	2012	1077	15.2	5.88	1933	1026	14.4	5.66
0.023	1786	844	16.1	5.17	1487	712	15.9	4.14
0.046	1768	909	14.9	5.06	1431	761	14.8	4.09
0.066	1422	723	14.1	3.91	1281	726	12.9	3.29
0.092	1216	684	13.6	3.44	988	634	11.7	2.66
- - - - - - - - - - - - - - - - - - % reduction from CF (0.023 ppm) treatment - - - - - - - - - - -								
0.046	1	(+7)	7	2	1	(+7)	7	1
0.066	20	14	12	24	18	(+2)	19	21
0.092	32	19	16	33	34	11	26	36

*Yields were averaged over four SO_2 treatments (0.02, 0.09, 0.30, 0.56 ppm, 4-h/day, 3 days/week).

**Weight of 100 seeds

†Seed weight/plant

††The values for the AA plot should not be compared with the 0.046 chamber plot, because chamber plot values have been averaged over four SO_2 levels.

Table 4.3.3.5. Effects of SO_2 on the yield of two soybean cultivars exposed for 4-h/day, 3 days/week in open-top chambers for 75 days*

	Amsoy-71				Corsoy-79			
SO_2 (ppm)	Kg/ha	# seeds	100 swt**	sw/p†	Kg/ha	# seeds	100 swt**	sw/p†
0.02 (AA)††	2012	1077	15.2	5.88	1933	1026	14.4	5.66
0.02	1810	860	16.2	5.21	1549	803	14.9	4.22
0.09	1566	872	13.8	4.34	1379	790	13.2	3.67
0.30	1586	841	14.1	4.39	1229	692	13.2	3.42
0.56	1228	637	14.7	3.63	1016	548	13.9	2.88
- - - - - - - - - - - - - - - - % reduction from the 0.02 ppm chamber treatment - - - - - - - - - -								
0.09	13	(+1)	15	17	11	2	11	13
0.30	12	2	13	16	16	14	11	19
0.56	32	26	9	30	34	32	7	32

*Yields were averaged over four O_3 treatments (0.023, 0.046, 0.066, 0.092 ppm, 7-h/day, 7 days/week).

**Weight of 100 seeds

†Seed weight/plant

††The values for the AA plot should not be compared with the 0.02 chamber plot, because the chamber plot values have been averaged over four O_3 levels.

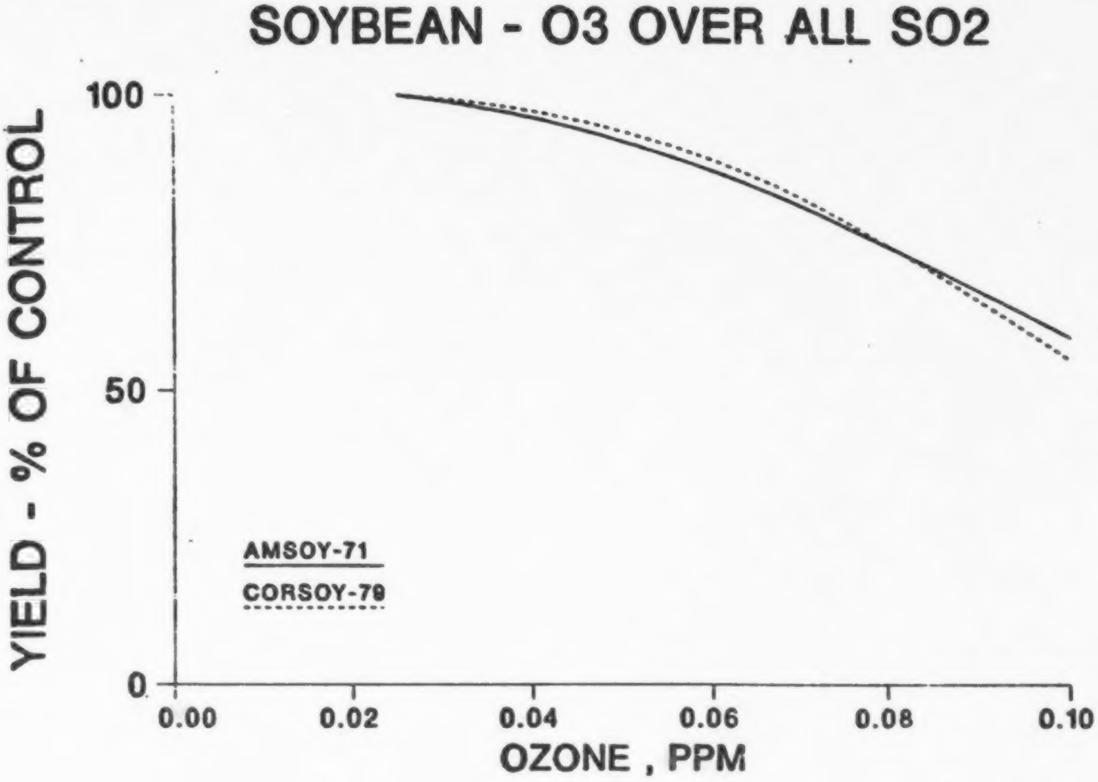


Figure 4.3.3.2. Relative soybean seed yield performance curves from the bivariate Weibull model for two soybean cultivars indicating seed yield as a function of 7-h/day seasonal mean O_3 concentration (across SO_2), using a reference O_3 concentration of 0.025 ppm. The effects of O_3 and SO_2 on yield were independent.

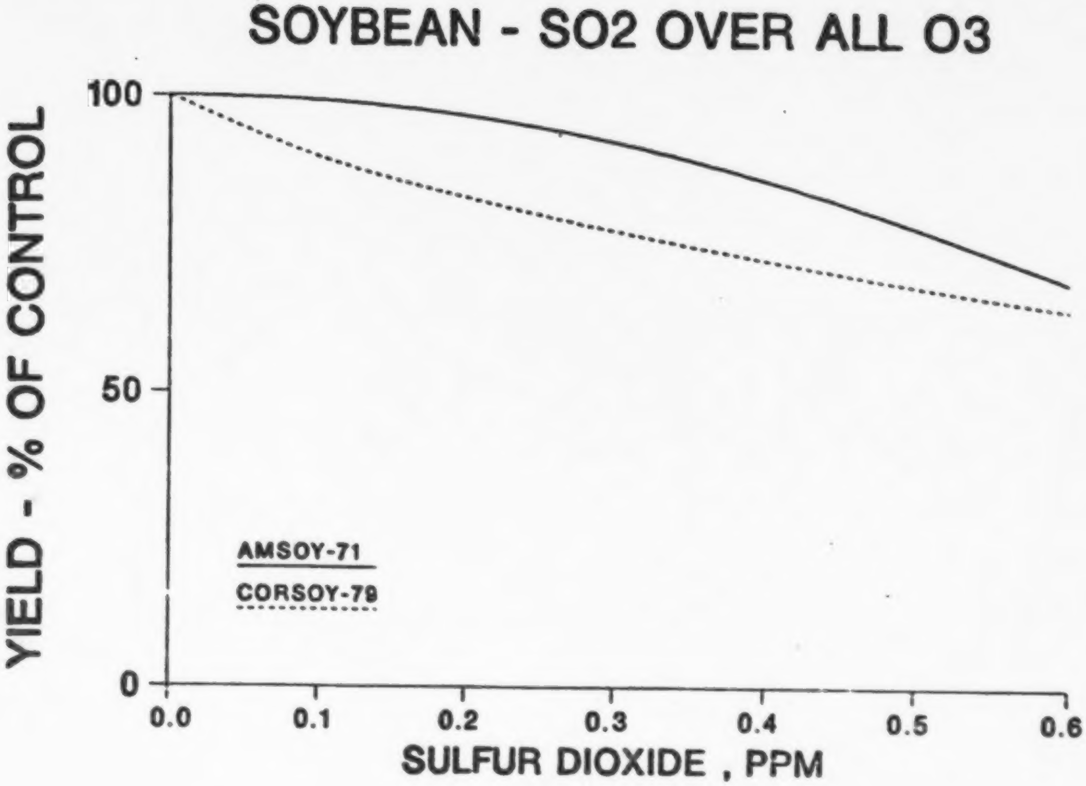


Figure 4.3.3.3. Relative soybean seed yield performance curves from the bivariate Weibull model for two soybean cultivars indicating seed yield as a function of the 4-h/day, 3 day/week seasonal mean SO_2 concentration (across O_3), using a reference SO_2 concentration of 0.00 ppm. The effects of SO_2 and O_3 on yield were independent.

$$Y = \alpha \cdot \exp\left[-\left(\frac{O3}{\sigma 1}\right)^{c1}\right] \cdot \exp\left[-\left(\frac{SO2}{\sigma 2}\right)^{c2}\right]$$

where alpha is the yield at 0.00 ppm O_3 (or SO_2) concentration; σ is the O_3 (or SO_2) concentration at which yield is 0.63 alpha; and c is a dimensionless shape parameter. The model parameters are given in Table 4.3.3.6. There was no indication of cultivar differences in yield response to the pollutants ($F = 0.13$). The bivariate Weibull model predicted that O_3-induced yield reductions averaged across both cultivars would be 12% at 0.06 ppm and 42% at 0.10 ppm compared to a control of 0.025 ppm O_3, at any of the SO_2 concentrations. Sulfur dioxide-induced yield reductions averaged across both cultivars were predicted to be 6.7% at 0.1 ppm, 17.4% at 0.3 ppm, and 32% at 0.6 ppm compared to a control of 0.0 ppm for any of the O_3 concentrations.

Conclusion. The actual and predicted O_3-induced yield reductions in this study are nearly identical to those noted for 'Corsoy-79' in 1980 (Kress and Miller, 1983). These results are also similar to those of Heagle et al. (1983) for O_3 and for the interaction of O_3 and SO_2. Our SO_2 exposure regime of somewhat higher concentrations in intermittent fumigations appeared to have less effect (about 45% less) on yield than their daily exposure regime. Our results indicating that O_3 affected seed weight equal to or greater than seed number while SO_2 affected primarily seed number, are also similar to the results of Heagle et al. (1983).

These results confirm the O_3 sensitivity of soybean. They also suggest that even low SO_2 concentrations (0.10 ppm) near a point source could cause substantial ($\cong$7%) yield reduction. These data will be combined with data from five other field sites for evaluation of the effects of O_3 on important agricultural crops. In areas where the potential for O_3 and SO_2 to co-occur exists, these data may be particularly useful.

4.4. QUALITY ASSURANCE FOR 1983--Grady Neely and James Miller

4.4.1. Air Monitoring

A systems evaluation of quality assurance (QA) procedures for instrumentation monitoring and dispensing of air pollutants was made 5-13 September at each of the five NCLAN sites by Grady Neely, NCLAN Quality Assurance Officer (QAO). He stated in his report, "No significant performance problems were encountered at any of the research locations. All sites seemed to have highly motivated personnel who were doing good research," as evidenced by personal communication and observation.

The annual performance audit of air monitoring analyzers at each NCLAN site was conducted 10 July through 5 August 1983, by Research Triangle Institute (RTI), Research Triangle Park, North Carolina 27711. The report entitled, "Fourth Performance Audit by National Crop Loss Assessment Network," by J. L. McKee and D. L. Biddison was conducted under EPA Contract No. 68-02-3767 and is on file with the QAO in Corvallis.

A summary of the analyzer audits for all research locations in 1980, 1981, 1982, and 1983 is shown in Table 4.4.1.1. A result of excellent,

Table 4.3.3.6. Parameters for the fitted bivariate Weibull equations for overall seed yield of two soybean cultivars exposed to O_3 (7-h/day, 7 day/week) and SO_2 (4-h/day, 3 day/week)

Parameter*	Amsoy-71	Corsoy-79	Combined
α	2008.5 (218.7)**	1822.5 (328.1)	1934.4 (189.3)
σ (for O_3, σ_1)	0.128 (0.031)	0.118 (0.024)	0.124 (0.020)
c (for O_3, c_1)	2.467 (1.785)	3.082 (2.200)	2.692 (1.358)
σ (for SO_2 σ_2)	0.934 (0.432)	1.703 (1.806)	1.543 (1.044)
c (for SO_2, c_2)	2.244 (1.935)	0.788 (0.870)	1.009 (0.703)

*α = seed yield at 0.00 ppm of O_3 or SO_2.

σ_1 and σ_2 = concentration in ppm at which yield is 0.37 alpha.

c_1 and c_2 = dimensionless shape parameters

**values in parentheses are one standard error.

Table 4.4.1.1. Summary of NCLAN analysis audits from 1980 through 1983*

Audit Site and Date	Ozone			Sulfur Dioxide			Nitrogen Oxides			Carbon Dioxide			
	E	S	U/I	E	S	U/I	E	S	U/I	E	S	U/I	Total
Raleigh													
Sept. 1980					1	1							2
July 1981		4		2	2				1				9
Sept. 1981	4			3	1				1				9
Sept. 1982	3	2		2			1						8
Sept. 1983	2	1			1		2						6
Beltsville													
July 1980			1		1								2
July 1981		1	1		2					1			5
Sept. 1981	2	1		1	1								5
Sept. 1982	3	2			1	1							7
Sept. 1983	5	1				1							7
Ithaca													
Sept. 1980	1	2	1	1	1								6
July 1981	4			2	2					1			9
Sept. 1981	5			1	3							1	9
Sept. 1982	4	1		2	2								9
Sept. 1983		4		2	2								8
Riverside													
Sept. 1980	1	4											5
July 1981	2	1	1										4
Argonne													
July 1981	2	3		2	3			1					11
Sept. 1981	3	1	1	2		3		1	1				12
Sept. 1982	1	2		1	1				1				6
Sept. 1983	2	1	2		3				1				9
Shafter													
Sept. 1981	3		1										4
Aug. 1982	2	2											4
Sept. 1983	2	2											4
Livermore													
Sept. 1981	5			4						1			10
Sept. 1982	4			2	2					1			9
Corvallis													
July 1980	2				1			1					4
July 1981	2			1				1					4
Sept. 1981	2			1			1						4
Sept. 1982	1	1			1		1						4
Sept. 1983	2			1				1					4
Totals													
Sept. 1980	4	6	4	1	4	1		1					21
July 1981	10	9	2	7	9			2	1	2			42
Sept. 1981	22	4	2	11	6	3	1	1	2	1		1	54
Sept. 1982	18	10		7	7	1	2		1	1			47
Sept. 1983	13	9	2	3	6	1	2	1	1				38

*E = Excellent; S = Satisfactory; U = Unsatisfactory; I = Inoperative.

satisfactory, or unsatisfactory indicates the response of the analyzer was within 5%, 5-15%, or greater than 15%, respectively, of the known amount of standard gas presented to the analyzer. Summary results for 1983 reveal for the twenty-four O_3 analyzers audited, thirteen were excellent, nine were satisfactory, and two were inoperative which did not alter data quality because backup instruments were available. Of the ten SO_2 instruments, three were excellent, six were satisfactory, and one was shut down. The results of the audit for the four total oxides of nitrogen monitors show each of the channels for nitric oxide, oxides of nitrogen, and nitrogen dioxide were excellent on two of the analyzers, one satisfactory, and one inoperative. No carbon dioxide analyzers were in use this year. A summary of NCLAN analyzer precision is shown in Table 4.4.1.2.

Deficiencies in calibration standards were noted at the various sites during the RTI instrumentation audit. These deficiencies were from using both tank gases and permeation tube standards which were past their certification date. Although John McKee of RTI pointed out "the tanks had not changed substantially in their concentrations" more precise data could be expected if the standards were recertified on a yearly basis. All sites are now aware of this potential problem and are using standards which are within their certification date.

Each site made sample line system efficiency checks of measured O_3 levels for each chamber and study in 1983. Results presented in Table 4.4.1.3. indicate O_3 monitors at all locations always measured at least 80% of the O_3 present. Each line efficiency percentage was used in calculating an efficiency factor to determine an accurate O_3 concentration to which the plants were subjected in each chamber and study.

4.4.2. Biological

This report summarizes the third year of results for NCLAN's Biological Quality Assurance Plan, BQAP. A systems evaluation of planned QA procedures was made at each research location September 5-13 by Grady Neely, NCLAN Quality Assurance Officer (QAO). Each station was following QA procedures for soil moisture and in weighing experimental plant material. The BQAP questionnaire was mailed by the QAO to the Biological Quality Assurance Leader (BQAL) for each site in January 1984 to determine how closely QA procedures were followed in 1983. The results indicate: 1) weighing QA procedures were adhered to at each location; however, three of the sites did not find it necessary to conduct a yearly maintenance check because daily calibration checks indicated the balances were operating within NCLAN's ± 1% tolerance; 2) QA procedures were followed at each site for soil moisture measurements, except one location failed to conduct an end of season uniformity check of irrometers which will be corrected in 1984; and 3) data handling procedures were being adhered to at all stations. All questionnaires will be maintained by the QAO.

A summary of checks for weight measurement accuracy, presented in Table 4.4.2.1., indicates all station weights were within 1% of their true weights at least 98% of the time. Four of the five stations were always within 1% of the true weight.

Table 4.4.1.2. Summary of NCLAN analyzer precision in 1983.

Site	Analyzer	Serial Number	Dates	Pts.	% Mean	Std. Dev.	95% Probability Limits	
							Upper	Lower
Argonne	Bendix/O_3	7503	5/03-10/28	76	-0.32	2.3	4.2	- 4.8
	Bendix/O_3	32977	6/11-09/24	33	-2.46	8.1	13.4	-18.3
	Bendix/O_3	300452	5/03-10/20	69	-0.03	3.0	5.8	- 5.8
	Bendix/O_3	2676115	7/27-10/13	32	-0.22	3.0	5.7	- 6.2
	Bendix/O_3	32937	5/03-10/17	64	-0.31	2.0	3.6	- 4.2
	Bendix/O_3	2676111	8/10-10/20	35	0.46	3.6	7.4	- 6.5
	Meloy/SO_2	7L115	6/15-10/13	13	0.18	6.4	12.8	-12.4
	Meloy/SO_2	7L154	6/15-10/13	14	-0.74	6.1	11.2	-12.1
	TECO/SO_2	ASM-3507-66	3/29-10/12	6	-2.32	3.72	5.0	- 9.6
Beltsville*								
Boyce Thompson	MLABS/O_3	331	6/17-09/21	26	0.86	6.6	13.8	-12.1
	MLABS/O_3	479	6/17-10/18	38	-0.72	6.2	11.5	-12.9
	MLABS/O_3	167	6/17-09/16	25	0.56	7.8	15.8	-14.7
	MLABS/O_3	169	6/17-08/29	25	1.43	11.6	24.1	-21.3
	MLABS/O_3	283	6/17-07/13	14	0.35	4.6	9.3	- 8.6
	TECO/SO_2	2383-53	6/21-07/13	11	-2.75	5.3	7.5	-13.0
	TECO/SO_2	8432100	6/21-08/16	22	-2.21	6.4	10.4	-14.9
	TECO/SO_2	569776	8/01-10/11	10	-1.80	2.9	3.9	- 7.5
	TECO/SO_2	9909113	6/21-10/11	34	-1.12	5.6	9.8	-12.1
	TECO/SO_2	9896113	6/21-08/19	23	3.63	6.6	16.6	- 9.3
Raleigh	Bendix/O_3	032759	06/01-08/29	28	-0.99	9.5	17.7	-19.7
	Bendix/O_3	071584	06/01-08/29	26	0.70	12.4	25.0	-23.6
	Bendix/O_3	071579	06/06-08/01	15	0.55	10.9	21.9	-20.8
	MLABS/O_3	284	08/01-08/29	13	0.18	11.2	22.1	-21.7

Table 4.4.1.2. Continued.

Shafter	Dasibi/O_3	1908	09/02-10/31	11	0.58	0.7	1.98	- 0.8
	Dasibi/O_3	1132	09/01-10/12	6	0.55	1.6	3.6	- 2.5
	Dasibi/O_3	1120	09/01-10/31	11	-0.24	1.0	1.7	- 2.1
	Dasibi/O_3	1140	09/01-10/31	6	0.11	0.6	1.4	- 1.2
	Dasibi/O_3	1140	02/04-04/24	17	-0.05	1.8	3.5	- 3.6
	Dasibi/O_3	1120	02/04-04/24	17	0.07	1.0	2.0	- 1.9
	Dasibi/O_3	1183	02/04-04/24	17	-0.17	1.0	1.8	- 2.2

*Zero and span checks were made on a weekly basis; however, the data were not recorded.

Table 4.4.1.3. Mean percent efficiencies for O_3 monitoring system lines by site and study in 1983*,**

Line #	Argonne		Beltsville	BTI	Raleigh		Shafter	
	Wheat[a]	Soybean[c]	Soybean[d]	Wheat[e]	Soybean[f]	Tobacco[f]	Barley[g]	Lettuce[g]
1	0.94	0.94	0.85	0.91	0.92	0.87	0.99	1.00
2	0.95	0.91	0.90	0.87	0.97	0.81	1.02	1.02
3	0.94	0.95	0.91	0.92	---	0.86	---	0.98
4	0.94	0.94	0.93	0.97	---	0.86	0.94	---
5	0.95	0.94	0.93	0.88	0.98	0.85	0.98	1.00
6	0.94	0.91	0.93	0.91	---	0.83	1.00	0.96
7	0.95	0.95	0.93	0.90	0.98	0.87	1.00	0.95
8	0.95	0.94	0.91	0.86	0.98	0.92	1.02	0.94
9	---	0.96	0.93	0.92	0.98	---	1.00	0.96
10	---	0.96	0.93	0.93	0.98	0.87	---	---
11	---	0.92	0.93	0.87	0.95	0.87	1.00	---
12	0.95	0.87[b]	0.91	0.95	0.94	0.87	1.00	1.00
13	0.95	0.82[b]	0.94	0.91	0.97	0.85	1.02	1.01
14	0.95	0.82[b]	0.89	0.96	---	0.89	1.01	0.98
15	0.95	0.82[b]	0.94	0.95	---	0.89	0.99	1.03
16	0.95	0.83[b]	0.93	0.96	---	0.90	---	0.96
17	0.95	0.83[b]	0.93	0.97	0.97	0.88	0.98	0.95
18	0.95	0.85[b]	0.95	0.85	---	0.88	1.02	0.96
19	0.95	0.81[b]	0.89	0.89	---	0.86	1.00	0.95
20	---	0.83[b]	0.93	0.93	0.96	0.09	1.02	0.98
21	---	0.84[b]	0.92	0.89	---	0.92	---	---
22	0.84[b]	0.91	0.94	0.91	---	0.87	0.99	1.00
23	0.83[b]	0.91	0.98	0.88	0.90	---	---	0.98
24	0.84[b]	0.91	0.97	0.83	0.93	0.87	0.98	1.00
25	0.84[b]	0.92	0.93		0.94		1.02	1.00
26	0.83[b]	0.91	0.94		0.91		0.99	0.95
27	0.84[b]	0.91	0.89		0.91		1.00	0.98
28	0.83[b]	0.92	0.88		---		1.01	0.99
29	0.84[b]	0.91	0.91		0.90		0.98	
30	0.84[b]	0.90	0.93		0.95			

Table 4.4.1.3. Continued

	Argonne**		Beltsville	BTI	Raleigh		Shafter	
Line #	Wheat[a]	Soybean[c]	Soybean[d]	Wheat[e]	Soybean[f]	Tobacco[f]	Barley[g]	Lettuce[g]
31	0.84[b]	0.90	0.91		0.89			
32	0.92	0.92	0.89		0.93			
33	0.92	0.92	0.92		---			
34	0.92	0.92	0.92		0.93			
35	0.93	0.92	0.92					
36	0.92	0.92	0.90					
37	0.92	0.92						
38	0.92	0.92						
39	0.92	0.92						
40	0.92	0.92						
41	0.92	0.92						

*(---) Indicates no line in use.

**Specific information for each study is shown for the following letter designations:

[a] Average of one to three sample line checks

[b] Lower efficiency due in part to ozone monitor

[c] Average of two to ten sample line checks

[d] Average of four sample line checks

[e] Average of two sample line checks

[f] Average of at least nine sample line checks

[g] Average of twenty sample line checks

Table 4.4.2.1. Summary of QA checks for weight measurements

Location	Total # Days Checked	Weights Checked	Mean % Accuracy	Range % Accuracy	% ≥ 99% Accurate
Argonne	6	62	99.99	100.1-100.0	100
Beltsville	2	30	99.97	100.1- 99.8	100
BTI	9	117	99.81	102.0- 98.0	98
Raleigh	4	36	99.90	101.0- 99.0	100
Shafter	2	18	99.94	100.1- 99.9	100

All sites are in compliance with NCLAN QA documentation requirements. The NCLAN QAO will work with all BQAL for each station in 1984 making necessary additions and updating the BQAP.

4.5. ASSESSMENT OF THE IMPORTANCE OF OBSERVATION FREQUENCY IN TIME-SHARING MONITORING SYSTEMS FOR O_3--Robert J. Kohut and Allen S. Heagle

4.5.1. Introduction

The NCLAN, open-top chambers are used to expose plants to controlled levels of O_3. An experiment may include as many as five replications of six O_3 treatments and thus employ 30 chambers. Expense and logistics make it infeasible to use separate O_3 monitors for each chamber and as a result, time-sharing systems are used. These systems use a single monitor to sequence through a number of chambers and provide one to three short-term, 2- to 3-minute duration, observations of pollutant concentrations in a chamber each hour. The length of the observations and their frequency vary with the specifics of the system at each NCLAN site. Concentrations of O_3 in open-top chambers are dependent upon interactions between ambient O_3 concentrations, the amount of O_3 added to the chambers, and ambient wind velocity which affects the rate of ingress of ambient air into the chambers. The accuracy with which time-sharing systems characterize the 1-h and 7-h O_3 concentrations in the chambers has not been evaluated. Thus, experiments were conducted by Boyce Thompson Institute in Ithaca, NY and USDA at North Carolina State University, Raleigh, NC to compare the O_3 concentrations obtained by sampling at different intervals in open-top chambers.

4.5.2. Materials and Methods

4.5.2.1. Boyce Thompson Institute

Two open-top chambers containing a mixture of timothy, red clover and birdsfoot trefoil were intensively monitored to collect data for the assessment. The O_3 levels selected for evaluation were nonfiltered air (NF) and an O_3-addition that was two times ambient. Monitoring was performed with Monitor Labs chemiluminescent O_3 monitors over a 40 day period in the chambers. The 2 x treatment chamber had a monitor system that provided 30 1-minute observations each hour. The NF air treatment chamber was part of a system that provided 15 2-minute observations each hour. Subsets of these data bases were used in the comparison. For two times treatment, data for 26-30 August and 4-7 and 16-19 September were selected. The data for the NF treatment were from 15-17, 26-29, August and 3 September. These periods were selected for comparison based on the daily variations in O_3 concentrations.

One-hour and 7-h O_3 concentration means were calculated for sampling frequencies of 1, 2, 3, 5, 10, and 30 observations per hour with the two times ambient treatment data set. The single observation was made at a set time for each hour and the 2, 3, 5, and 10 observations were evenly spaced throughout the hour to simulate the systematic nature of the time-sharing process. The same approach was used with the nonfiltered treatment data for frequencies 1, 2, 3, 5, and 15 observations per hour.

4.5.2.2. USDA at North Carolina State University

One open-top chamber containing full-grown soybean was used in the study. The soybeans were planted in N-S rows spaced 1-m and were about 1.2 m tall. The chamber was positioned so that the center of the plot was midway between two rows and the chamber fan and door were at the north and south side of the chamber, respectively. A constant amount of O_3 was added to the O_3 in ambient air at the inlet duct of the chamber for 7-h/day (0900-1600 EST) to produce a mean concentration in the chamber of about 0.04 ppm higher than the ambient O_3 level. Two sampling lines were placed in the center of the chamber at canopy height. One sample line was attached directly to a Monitor Labs chemiluminescent O_3 monitor from which instantaneous values were obtained every 5 minutes. The other line was used with another Monitor Labs instrument in a time-sharing monitoring system which sampled the O_3 concentration once each 45 min. Each 45-min observation was the mean of four to six instantaneous values taken at 10-second intervals during the last minute of a 3-minute switching interval.

From 15 August to 15 September, daily 7-h (0900 to 1600) mean O_3 concentrations were calculated from the continuous monitor using the 84 instantaneous values and from the time-share system using the nine 1-minute mean values. The instantaneous values from the continuous monitor that occurred nearest in time to each of the nine values from the time-share monitor were used to calculate a daily correction factor to account for differences in instrument performance. The daily correction factor was applied to the 7-h average calculated from the 84 continuous values.

4.5.3. Results

4.5.3.1. Boyce Thompson Institute

The 1-h and 7-h average O_3 concentrations for the various sampling frequencies are presented in Tables 4.5.1. and 4.5.2. All of the sampling frequencies provided similar hourly and daily O_3 concentrations. The hourly values derived from one observation per hour depart at most 45% from those produced with 15 or 30 observations, but the 7-h mean values generated from one observation per hour depart less than 7% from those produced with 15 or 30 observations. Observation frequencies of two or three per hour produce 1-h averages that are almost identical to those from 15 or 30 observations. The 7-h means for the 13-day (Table 4.5.1.) and 8-day (Table 4.5.2.) periods are also almost identical regardless of the number of observations per hour.

4.5.3.2. USDA at North Carolina State University

Individual data points for 5- and 45-minute sampling intervals are shown for a relatively calm day (Figure 4.5.1.) and for a relatively windy day (Figure 4.5.2.). For the 31-day sampling period, the daily 7-h means calculated by 45-minute interval sampling were always within 5% of the daily means calculated by 5-minute interval sampling (Table 4.5.3.). The 31-day mean of the daily 7-h means was 0.1042 ppm for the 5-minute interval and 0.1041 ppm for the 45-minute interval. Of the nine observations per day obtained with the 45-minute sampling interval, those taken closest to 1100 and 1300 hr were used to assess the utility of using one and two observations to characterize 7-h means (Table 4.5.3.). Although the daily

Table 4.5.1. One hour and 7-h mean O_3 concentrations as determined by various numbers of observations per hour in a two times ambient treatment (all concentrations in ppm)

Date	#OBS	1100	1200	1300	1400	1500	1600	1700	Mean
8/26	1	.149	.104	.142	.148	.137	.071	.117	.124
	2	.118	.104	.132	.131	.144	.121	.122	.124
	3	.139	.115	.134	.144	.143	.121	.115	.129
	5	.106	.098	.133	.138	.131	.135	.106	.121
	10	.113	.106	.129	.137	.137	.127	.114	.123
	30	.113	.103	.132	.138	.134	.129	.115	.123
8/27	1	.079	.140	.129	.151	.138	.176	.156	.138
	2	.128	.143	.153	.153	.138	.156	.167	.148
	3	.107	.142	.124	.153	.139	.162	.162	.142
	5	.094	.143	.133	.140	.135	.160	.171	.139
	10	.102	.140	.130	.145	.140	.145	.163	.138
	30	.100	.139	.135	.146	.140	.151	.163	.139
8/28	1	.108	.108	.132	.121	.128	.088	.102	.113
	2	.104	.100	.132	.131	.117	.100	.095	.112
	3	.101	.109	.132	.126	.118	.084	.098	.110
	5	.095	.106	.126	.123	.116	.092	.093	.106
	10	.092	.108	.127	.119	.101	.093	.093	.105
	30	.093	.106	.129	.121	.123	.093	.093	.106
8/29	1	-	.093	.134	.089	.092	.100	.086	.100
	2	-	.111	.129	.087	.100	.096	.096	.103
	3	-	.100	.130	.092	.088	.097	.093	.100
	5	-	.094	.121	.092	.092	.087	.097	.097
	10	-	.105	.127	.090	.090	.092	.086	.100
	30	-	.100	.124	.092	.089	.090	.085	.097
8/30	1	.055	.068	.040	.032	.012	.010	.012	.033
	2	.056	.067	.050	.035	.014	.010	.012	.035
	3	.061	.066	.043	.033	.013	.011	.012	.034
	5	.056	.064	.044	.033	.012	.010	.011	.033
	10	.057	.065	.046	.034	.020	.010	.011	.033
	30	.057	.065	.046	.033	.013	.010	.011	.033
9/4	1	.172	.172	.150	.190	.169	.115	.176	.164
	2	.156	.163	.173	.183	.173	.138	.171	.166
	3	.157	.162	.166	.190	.164	.127	.119	.155
	5	.143	.160	.159	.177	.163	.138	.170	.158
	10	.143	.161	.167	.181	.164	.139	.167	.161
	30	.144	.161	.164	.183	.162	.139	.168	.160

Table 4.5.1. Continued

Date	#OBS	1100	1200	1300	1400	1500	1600	1700	Mean
9/5	1	.142	.142	.103	.117	.138	.147	.126	.131
	2	.129	.138	.114	.137	.117	.142	.108	.127
	3	.130	.138	.118	.127	.121	.128	.135	.128
	5	.151	.134	.117	.122	.118	.133	.127	.129
	10	.116	.131	.119	.121	.121	.135	.126	.124
	30	.132	.131	.116	.127	.119	.135	.126	.127
9/6	1	.124	.092	.118	.161	.127	.150	.165	.130
	2	.130	.122	.150	.132	.123	.136	.154	.134
	3	.124	.099	.122	.132	.143	.157	.147	.128
	5	.109	.109	.114	.123	.129	.146	.151	.126
	10	.113	.113	.125	.137	.126	.146	.145	.127
	30	.107	.110	.126	.131	.129	.149	.149	.127
9/7	1	.124	.117	.138	.161	.107	.142	.120	.130
	2	.130	.122	.128	.140	.121	.138	.112	.128
	3	.124	.120	.140	.140	.119	.136	.135	.131
	5	.109	.129	.139	.146	.130	.135	.118	.130
	10	.113	.129	.134	.145	.128	.136	.136	.131
	30	.107	.128	.134	.139	.130	.135	.135	.130
9/16	1	-	.061	.071	.071	.109	.109	.130	.092
	2	-	.079	.074	.095	.105	.101	.126	.097
	3	-	.087	.076	.086	.112	.113	.126	.100
	5	-	.081	.074	.100	.106	.100	.134	.100
	10	-	.072	.080	.090	.112	.104	.124	.097
	30	-	.076	.078	.094	.111	.106	.124	.098
9/17	1	.073	.118	.119	.112	.121	.135	.104	.112
	2	.074	.090	.109	.123	.129	.143	.107	.111
	3	.073	.112	.107	.115	.120	.132	.102	.109
	5	.073	.103	.110	.119	.123	.134	.085	.107
	10	.077	.103	.107	.106	.122	.136	.103	.109
	30	.076	.104	.107	.118	.122	.134	.105	.110
9/18	1	.109	.127	.094	.115	.109	.086	.097	.105
	2	.113	.127	.121	.111	.126	.094	.106	.114
	3	.107	.110	.104	.109	.113	.094	.105	.106
	5	.102	.120	.122	.106	.121	.100	.106	.112
	10	.101	.123	.110	.109	.118	.096	.109	.110
	30	.100	.119	.107	.107	.119	.097	.106	.109

Table 4.5.1. Continued

Date	#OBS	1100	1200	1300	1400	1500	1600	1700	Mean
9/19	1	.086	.098	.098	.131	.129	.119	.106	.110
	2	.098	.100	.114	.110	.120	.118	.111	.101
	3	.102	.100	.105	.130	.120	.122	.107	.123
	5	.099	.093	.113	.118	.123	.123	.110	.112
	10	.095	.097	.118	.119	.122	.123	.106	.112
	30	.096	.099	.116	.120	.123	.124	.103	.112
7-h mean for the 13-day subsample period									
	1	.114							
	2	.115							
	3	.115							
	5	.113							
	10	.113							
	30	.113							

Table 4.5.2 One-hour and 7-hour mean O_3 concentrations as determined by various numbers of observations per hour in a nonfiltered chamber (all concentrations in ppm)

Date	#OBS	1100	1200	1300	1400	1500	1600	1700	Mean
8/15	1	.032	.050	.055	.060	.058	.064	.060	.054
	2	.037	.045	.056	.058	.065	.059	.065	.054
	3	.034	.045	.053	.059	.060	.062	.064	.054
	5	.035	.045	.054	.060	.060	.059	.064	.054
	15	.033	.047	.055	.059	.061	.061	.064	.054
8/16	1	.056	.057	.065	.075	.078	.087	.080	.072
	2	.051	.058	.060	.068	.078	.086	.090	.070
	3	.054	.059	.061	.073	.078	.084	.085	.070
	5	.056	.059	.060	.070	.076	.084	.089	.070
	15	.052	.060	.060	.069	.077	.085	.087	.070
8/17	1	.069	.077	.126	.111	.125	.130	.128	.109
	2	.070	.083	.117	.117	.122	.136	.128	.111
	3	.069	.083	.117	.114	.124	.135	.127	.110
	5	.068	.086	.119	.115	.125	.136	.126	.111
	15	.069	.083	.118	.116	.125	.135	.130	.111
8/26	1	.062	.072	.072	.087	.080	.056	.061	.070
	2	.068	.068	.080	.086	.083	.062	.064	.073
	3	.064	.069	.076	.086	.081	.061	.066	.072
	5	.065	.068	.080	.086	.083	.060	.064	.073
	15	.065	.068	.077	.086	.081	.061	.066	.072
8/27	1	.064	.064	.077	.084	.092	.095	.093	.082
	2	.054	.067	.070	.082	.090	.093	.100	.078
	3	.056	.066	.073	.082	.087	.093	.095	.078
	5	.053	.067	.072	.082	.087	.094	.100	.080
	15	.052	.067	.072	.081	.087	.094	.099	.078
8/28	1	.037	.050	.053	.062	.053	.057	.054	.052
	2	.036	.047	.054	.057	.056	.051	.053	.051
	3	.036	.047	.052	.059	.053	.054	.052	.051
	5	.036	.045	.053	.057	.054	.054	.053	.051
	15	.036	.047	.052	.058	.054	.053	.053	.051

Table 4.5.2. Continued

DATE	#OBS	1100	1200	1300	1400	1500	1600	1700	MEAN
8/29	1	-	.028	.041	.041	.051	.044	.041	.041
	2	-	.027	.042	.042	.044	.049	.041	.040
	3	-	.028	.040	.040	.047	.043	.040	.040
	5	-	.030	.041	.041	.045	.043	.041	.040
	15	-	.030	.041	.041	.045	.044	.040	.040
9/3	1	.031	.050	.066	.064	.077	.081	.085	.065
	2	.036	.056	.061	.068	.075	.082	.082	.066
	3	.035	.052	.062	.065	.076	.080	.084	.065
	5	.039	.056	.064	.066	.077	.080	.083	.066
	15	.035	.053	.064	.066	.075	.080	.084	.065

7-h mean for the 8-day subsample period

1	.068
2	.068
3	.068
5	.068
15	.068

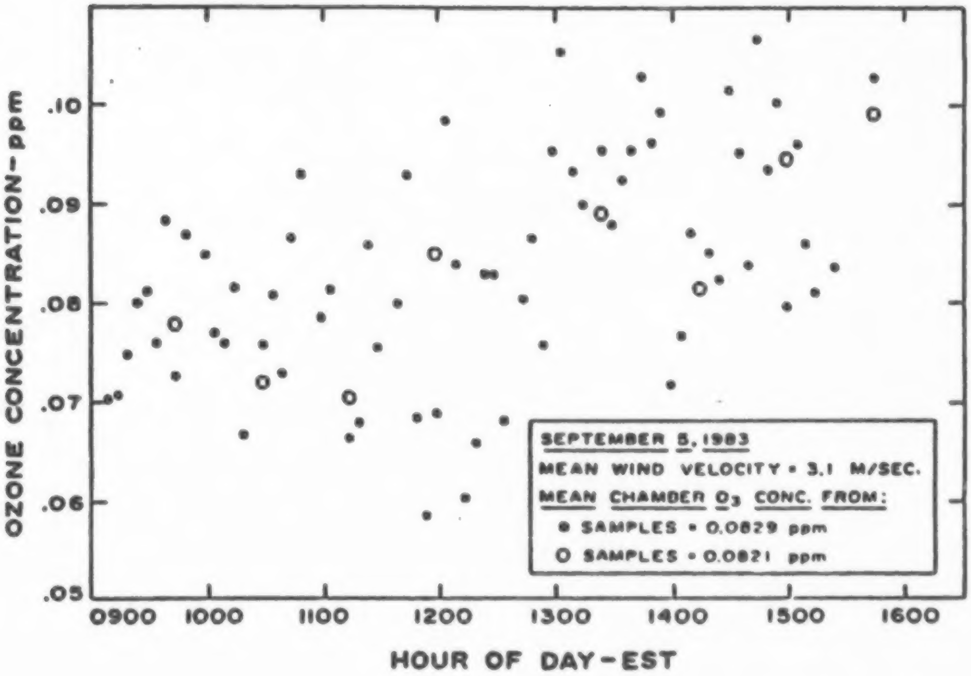


Figure 4.5.1. Comparison of the observations of O_3 concentrations obtained with 5-minute (●) and 45-minute (o) sample intervals on a day with high winds; a constant 0.04 ppm O_3 was added to the chamber.

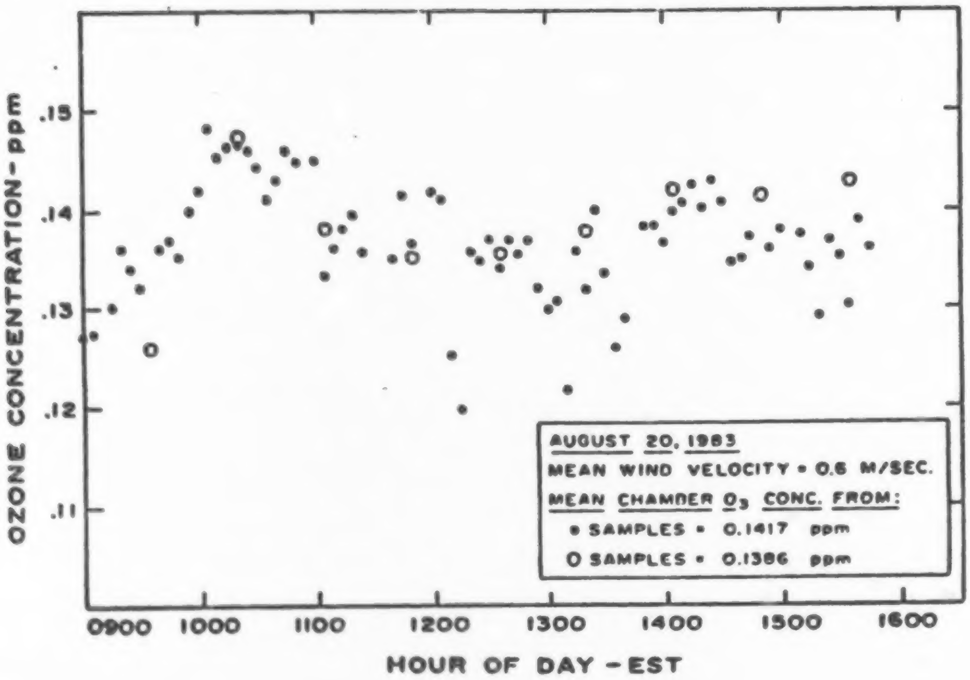


Figure 4.5.2. Comparison of the observations of O_3 concentrations obtained with 5-minute (●) and 45-minute (o) sample intervals on a day with low winds; a constant 0.04 ppm O_3 was added to the chamber.

Table 4.5.3. Relationships between 7-h per day mean O_3 concentrations in an open-top field chamber obtained by sampling at different intervals. (All concentrations in ppm)*

Date** 1983	Mean Wind Velocity 0900 - 1600 h- m/s	7-h per day Means Based on:				
		5-min Sample Interval	45-min Sample Interval			
		Mean of 84 Values	Mean of 7 to 9 Values	One Value at 1100 h	One Value at 1300 h	Mean of the 1100 and 1300 Values
Aug						
15	1.5	.1261	.1260	.1230	.1217	.1224
16	1.5	.1368	.1439	.1339	.1632	.1486
17	1.0	.1447	.1488	.1342	.1512	.1427
18	2.5	.1144	.1162	.0977	.1304	.1141
19	1.5	.1376	.1370	.1488	.1200	.1344
20	0.6	.1417	.1386	.1384	.1357	.1371
21	1.3	.1332	.1363	.1394	.1323	.1359
22	-	.0856	.0853	.0791	.1141	.0966
23	1.2	.1051	.1057	.0933	.1077	.1005
24	1.7	.0477	.0477	.0462	.0472	.0467
25	2.4	.0953	.0964	.0910	.0925	.0918
26	1.2	.0696	.0708	.0608	.0670	.0639
27	1.3	.0721	.0735	.0636	.0744	.0690
28	1.4	.0621	.0629	.0650	.0705	.0678
29	2.2	.0944	.0942	.0968	.1007	.0988
30	1.5	.1222	.1253	.1024	.1378	.1201
31	-	.1141	.1139	.1121	.1325	.1223

Table 4.5.3. Continued

Date** 1983	Mean Wind Velocity 0900 - 1600 h- m/s	7-h per day Means Based on: 5-min Sample Interval: Mean of 84 Values	45-min Sample Interval: Mean of 7 to 9 Values	One Value at 1100 h	One Value at 1300 h	Mean of the 1100 and 1300 Values
Sept						
1	1.7	.1107	.1068	.1010	.1118	.1064
2a/	3.0	.0384	.0384	.0371	.0408	.0390
3	1.0	.1037	.1041	.1087	.1143	.1115
4a/	2.4	.0368	.0324	.0307	.0383	.0345
5	3.1	.0829	.0821	.0705	.0687	.0696
6a/	3.4	.0674	.0674	.0395	.0433	.0414
7	1.4	.1228	.1252	.1337	.1346	.1342
8	2.7	.1285	.1289	.1234	.1382	.1308
9	0.7	.1481	.1460	.1471	.1560	.1516
10	1.7	.1332	.1274	.1394	.1462	.1428
11	2.2	.1501	.1491	.1541	.1535	.1538
12	2.4	.1104	.1086	.1208	.1090	.1149
13	1.0	.1069	.1042	.0934	.1078	.1006
14b/	-	-	-	-	-	-
15	3.8	.0871	.0837	.0729	.0856	.0793
Means		.1042	.1041	.0999	.1080	.1040

*Sampling was done in a non-filtered chamber to which a constant amount of O_3 was added above ambient (0.04 ppm).

**Rain precluded O_3 dispensing (a).

On 14 September the computer was not used to acquire data because of potential electrical damage from thunderstorms. (b) means calculated with one or two observations depart somewhat from those produced with 84 observations, the 7-h means for the 31-day period calculated by both methods are quite similar. The 7-h mean (for 31 days) calculated with 84 observations per day was 0.1042 ppm, the mean of the 1100 hr observations was 0.0999 ppm, the mean of the 1300 hr observations was 0.1080 ppm. The mean for the 1100 and 1300 hr observations was 0.1040 ppm (Table 4.5.3.).

4.5.4. Discussion

The similarity in results from different sampling intervals is a result of the generally gradual changes in O_3 concentrations during the day and the random short-term variations that occur within any hour. The degree of similarity between results from frequent and infrequent sampling intervals will be directly proportional to the duration of the sampling period (days) and inversely proportional to the degree of fluctuation in the concentration. Since the index of O_3 exposure used in the NCLAN studies is the seasonal 7-h O_3 mean, the time-sharing approach accurately characterizes this parameter. Identification of the maximum 7-h and 1-h O_3 concentrations during the exposure period should also be quite accurate, particularly if there are two or three observations per hour.

SECTION 5

CROP LOSS AND ECONOMIC ASSESSMENT

5.1. MODELING THE EFFECT OF DROUGHT ON CROP SENSITIVITY TO O_3--David King, Michael Snow - University of Portland)

5.1.1. Introduction

The impact of O_3 on crop growth and yield may be influenced by a number of environmental factors (Heck et al., 1977). To best estimate the impact of different O_3 scenarios on crop yield, NCLAN has attempted to duplicate field conditions in its experiments, where feasible. However, supplemental water has frequently been applied to alleviate drought stress in order to provide more uniform experimental conditions and to guard against crop failure due to drought. Drought stress frequently depresses yields in the East and Midwestern U.S. (Huff and Neil, 1982) and drought has been observed to reduce oxidant injury to field-grown tobacco (Dean and Davis, 1967).

Two general approaches may be taken to estimate the possible bias caused by differences between field and experimental water status. One approach would be to conduct unwatered experiments (at the eastern and midwestern NCLAN sites). Such experiments might require replication for a number of years and additional experimental sites to span the natural variability in drought severity and the timing of drought. A second approach would be to use the results of more controlled drought x O_3 experiments along with published plant-water relationships to model the crop response to O_3 under field water conditions. The second approach may demand less grandiose experiments, but is subject to the uncertainties of extrapolating beyond experimental conditions. The uncertainty involved in the modeling approach depends on how well the system being modeled is understood and on the "regularity" of its behavior.

This report presents a model-based approach for estimating the impact of moisture stress on crop sensitivity to O_3. The central feature of the approach is a soil water and crop transpiration model which is described below. The model is similar to that of Hanks (1974), but has been modified to include O_3 effects on transpiration and rooting. The postulated O_3 interactions are based partly on results from the CERL O_3 x water stress study and on published O_3 effects. The model will be upgraded as further CERL and NCLAN results become available. Preliminary results presented here illustrate the behavior of the model.

5.1.2. Approach

NCLAN results to date show a range of effects regarding the impact of drought on O_3-caused yield losses. However, most results suggest that drought changes the yield response to O_3. Conversely, O_3 damage to crops may influence their subsequent use of water. We expect a two-way interaction between water stress and O_3, with water stress affecting O_3 damage and O_3 damage influencing subsequent water use and soil moisture content. To account for this two-way interaction one needs an estimate of daily soil-water status throughout the season. Existing soil-water models could provide this estimate if they can be modified to incorporate the effect of O_3 damage on crop transpiration.

One then requires a method for calculating the effect of daily water stress and O_3 damage on final yield. The effect of drought on yield has been calculated by a number of methods ranging from statistical models to detailed crop simulators. However, a simple, general approach is preferable to meet our goal of assessing drought-pollutant interactions across large regions for a number of crops. A promising approach is that of Hanks and Hill (1980) which estimates yield in terms of seasonal crop transpiration. Transpiration is frequently computed by soil-water models as part of the process of determining the soil-water budget. Furthermore, one only requires very general crop characteristics, such as the relationship between crop transpiration and pan evaporation, in order to estimate seasonal transpiration.

Results from irrigation experiments suggest that total dry matter production is proportional to seasonal transpiration for a given crop, location, and year (Hanks, 1983). Thus one can express total dry matter yield as

$$Y = ST \times TE \tag{1}$$

where ST is seasonal transpiration and TE is the transpiration efficiency (Y/ST) for the crop, location, and year under consideration. (Symbols for the complete model are defined in Table 5.1.1.) Marketable yield (as opposed to dry matter yield) may vary with the timing of drought as well as with seasonal transpiration. However, equation (1) is being used in the initial model development. Variation in transpiration efficiency between localities and crops need not be considered here, as we are only interested in the relative changes in the O_3-caused loss due to drought.

We are constructing a simple, empirical model of crop transpiration that will be able to calculate both ST and TE for crops experiencing any pattern of rainfall and O_3 exposure. The completed model will use representative O_3 and weather records from the regions of interest to provide estimates of the impact of naturally-occuring drought on O_3-caused crop loss. We hope to establish a general relationship between severity of drought and modification of the O_3 effect so that the model need not be run for all combinations of weather and O_3. Once this general relationship is established one need only characterize drought for the regions of interest in order to correct crop loss assessments for the occurrence of drought. One can characterize the effect of drought on seasonal transpiration and yield by running the model with weather data from representative sites across a region. Drought may also be characterized by using published relationships between crop yield, rainfall, and temperature, or by using drought estimates generated by firms involved in forecasting crop yields.

5.1.3. The Soil-Water and Transpiration Model

Our approach for modeling transpiration follows that of Hanks and Hill (1980), which involves partitioning evapotranspiration between transpiration of water through the crop and surface evaporation. A similar approach was used by Hill et al. (1979) to successfully estimate the effect of drought on plot-grown soybean yields in Missouri. Actual crop

Table 5.1.1. Definitions of symbols

Symbol	Definitions
ASW	Plant available water in the crop rooting zone
B	Ratio of ASW/PSW below which soil water limits transpiration
D	Daily O_3 dose
Dh	Hourly O_3 dose
F_c	Factor accounting for chronic effect of O_3 on transpiration
F_t	Factor accounting for transient effect of O_3 on transpiration
OF	Factor accounting for drought protection against O_3
PET	Daily potential evapotranspiration
PSW	Potential available soil water at field capacity
PT	Daily potential transpiration
ST	Seasonal crop transpiration
T	Daily transpiration
T_o	Daily transpiration for crop exposed to negligible O_3
TE	Transpiration efficiency
TE_o	Transpiration efficiency for crop exposed to negligible O_3
Th	Ozone damage threshold
Y	Marketable yield
α	Factor accounting for repair and compensation for O_3 damage
β_1	Constant indicating transient effect of O_3 on transpiration
β_2	Constant indicating chronic effect of O_3 on transpiration
	Constant indicating effect of O_3 on TE vs. ST

transpiration is expressed as a fraction of the potential transpiration which would occur from an adequately-watered, nonpolluted crop. We assume that transpiration is reduced by low soil water availability and/or by past and present O_3 exposures.

It is convenient to visualize crop available soil water (ASW) as the central variable of the model, as shown in Figure 5.1.1. The daily change in available soil water (ΔASW) is given by

$$\begin{aligned} \text{ASW} &= \text{daily rainfall} + \text{water available by root } O_3 \text{ extension} \\ &\quad - \text{transpiration} - \text{surface evaporation} - \text{runoff} - \text{drainage} \qquad (2) \end{aligned}$$

where all variables are expressed on a per day basis. The rate of root zone extension is assumed to decrease with increasing O_3 damage to the crop due to a decrease in the overall crop growth rate with increasing O_3 damage. For a well-watered, nonpolluted crop with a wet soil, surface evaporation is assumed to be that fraction of potential evapotranspiration not accounted for by transpiration. As the soil surface dries, surface evaporation decreases below this wet surface value.

Seasonal crop transpiration is calculated on a per unit ground area basis as the sum of each day's transpiration. To simulate daily transpiration the model keeps track of potential evapotranspiration, surface evaporation, crop growth stage, plant available soil water, O_3 exposure, rainfall, runoff, and drainage. The functional relationship between transpiration and the variables which affect it is indicated as follows:

$$T = f(\text{PET, crop growth stage, ASW, } O_3 \text{ exposure}) \qquad (3)$$

where T is daily transpiration per unit ground area, PET is the daily potential evapotranspiration which would occur from a nonpolluted, well-watered crop, and ASW is plant available soil water. (ASW = total root zone water - remaining root zone water at the permanent wilting point.)

The variables affecting transpiration are in turn functions of other variables as indicated below:

$$\text{PET} = f(\text{weather}) \qquad (4a)$$

$$\text{crop growth stage} = f(\text{time and/or weather}) \qquad (4b)$$

$$\begin{aligned} \text{ASW} = f(&\text{rainfall, rooting zone depth, transpiration,} \\ &\text{surface evaporation}) \qquad (4c) \end{aligned}$$

Daily transpiration is computed using the following multiplicative expression:

$$T = \text{PET} \cdot (\text{PT}/\text{PET}) \cdot (T_o/\text{PT}) \cdot (T/T_o) \qquad (5)$$

where PT is potential transpiration for a well-watered, nonpolluted crop, T_o is the transpiration which would occur for a nonpolluted crop with the same available soil water as the crop being modeled, and T is estimated transpiration for the polluted and drought-stressed crop being modeled. All of the above quantities are expressed as daily values per unit ground

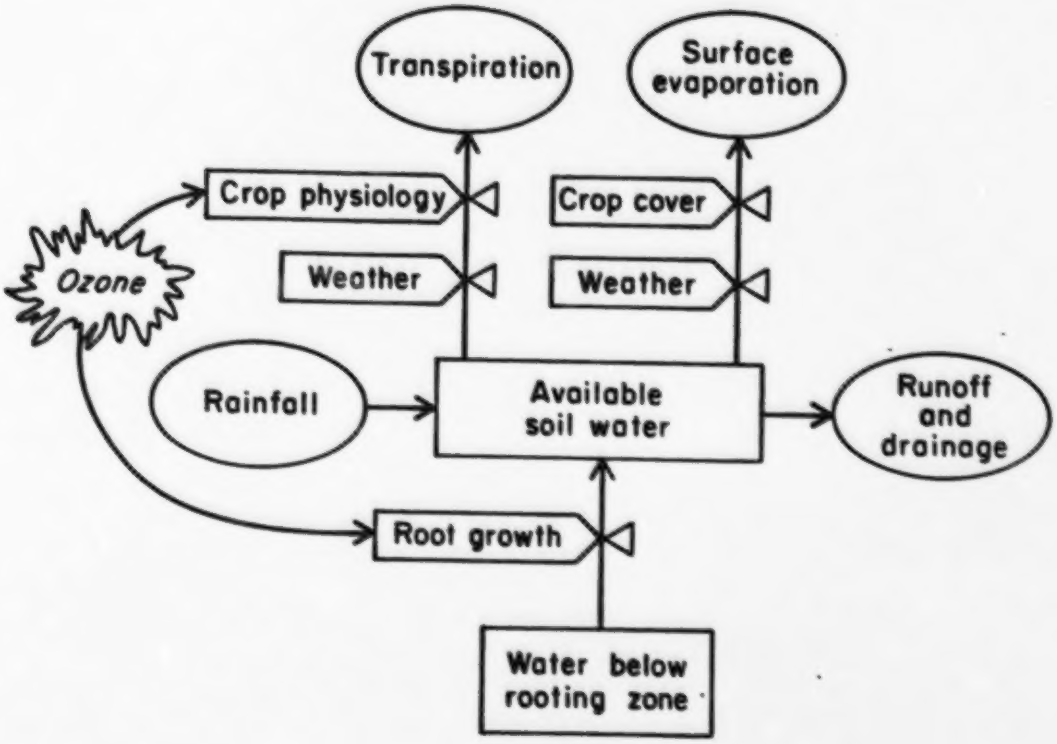

Transpiration
Surface evaporation
Crop physiology
Crop cover
Ozone
Weather
Weather
Rainfall
Available soil water
Runoff and drainage
Root growth
Water below rooting zone

Figure 5.1.1 Diagram of soil water and transpiration model.

area. The ratio (PT/PET) in equation (5) depends on crop growth stage and varies from zero before plant emergence to nearly 1.0 when the crop reaches full cover. (PT/PET) is initially assumed to depend only on time.

The ratio (T_o/PT) depends on soil water availability. Following Hanks and Hill (1980) we set

$$T_o/PT = 1, \text{ if } ASW/PSW \geq B \qquad (6a)$$

$$T_o/PT = ASW/(B \cdot PSW), \text{ if } ASW/PSW < B \qquad (6b)$$

where PSW is available soil water at field capacity and B is the value of ASW/PSW where soil water begins to limit transpiration. Measurements cited by Kanemasu et al. (1976) suggest that B = 0.3 for soybeans, but B is expected to vary with soil physical properties.

5.1.4. Effect of O_3 on Transpiration

The ratio of transpiration for O_3-damaged vs. undamaged crops (T/T_o) depends on past and present O_3 exposures and is calculated from the daily O_3 dose described below:

$$Dh = [O_3] - Th, \text{ for } [O_3] > Th \qquad (7a)$$

$$Dh = 0, \text{ for } [O_3] \leq Th \qquad (7b)$$

where Dh is hourly O_3 dose, $[O_3]$ is hourly O_3 concentration, and Th is an O_3 threshold which must be exceeded before transpiration is affected. For the example calculations which follow, the threshold was set at 0.04 ppm (Table 5.1.2.). The daily dose (D) is then defined over the period during which the stomata are open as

$$D = \sum_{8\text{ am}}^{6\text{ pm}} Dh \qquad (8)$$

where the above time frame is appropriate for California-grown cotton (Taylor et al. this report; Heck et al. 1983a).

We assume that O_3 can have a transient effect on transpiration by directly influencing stomatal conductance and a chronic effect caused by damage to leaf cells. These two processes appear to affect conductances of plants exposed to acute O_3 episodes, but are difficult to quantify under ambient conditions. For the case where water stress does not affect transpiration the transient effect is computed as

$$F_t = \beta_1 D \qquad (9)$$

where β_1 is a constant reflecting the direct response of stomata to O_3. The chronic effect is modeled as

$$F_c = (1-\alpha)\, F_c' + \beta_2 D \qquad (10)$$

Table 5.1.2. Values of the adjustable model parameters used to produce the preliminary results

Parameter	Value
Planting Date	May 22
Season Length	127 days
PSW	16 cm
Pot. avail. water for evaporation in surface layer	1.6 cm
B	0.3
Th	0.04 ppm
α 1/	0.1 for $d \leq 45$ $0.1(1 - \frac{d-45}{45})$, for $45 < d < 90$ 0, for $d \geq 90$ where d is days after planting
β_1	0.0832 ppm
β_2	0.0208 ppm
γ	1.0

1/ These values for are for the case of no O_3 or water stress. If water stress or O_3 damage occurs then $\alpha' = \alpha(T/PT)$ where α' is the value of α adjusted to account for the effects of stresses on repair and compensation for O_3 damage.

where F_c is the chronic effect of O_3 on transpiration on a given day, F_c' is the chronic effect for the previous day, α is a factor accounting for repair and/or compensation for O_3 damage, and β_2 is a constant reflecting the chronic response to current O_3. If repair and/or compensation for O_3 damage occurs then $\alpha > 0$, otherwise $\alpha = 0$. In the present model α depends on crop growth stage and on crop water status, as these factors are expected to influence repair and compensation. For the results which follow, $\alpha = 0.1$ for the vegetative growth stages. Thus, 90% of the previous day's damage is carried forward to the current day according to equation (10). Compensation is assumed to decline later in the season as leaf growth declines (Table 5.1.2.).

The relative importance of chronic vs. transient effects can be altered in the model by adjusting β_1 and β_2. The chronic effect on transpiration is assumed to be dominant in the current version of the model, consistent with recent CERL results. The ratio of polluted to nonpolluted transpiration on any given day is then

$$T/T_o = 1 - F_t - F_c \qquad (11)$$

for a given soil moisture level.

Because both transpiration and O_3 uptake are mediated by stomatal aperture, drought should affect the O_3 damage process when it affects transpiration. We shall assume that drought provides protection against O_3 which is equivalent to lowering the external O_3 concentration for an adequately watered crop. That is, moisture stress lowers daily O_3 uptake by the same fraction as it lowers daily transpiration. If $ASW/PSW < B$ so that transpiration is reduced, then

$$OF = ASW/(B \cdot PSW) \qquad (12)$$

where OF is a factor (less than 1) which multiplies the external O_3 concentration to account for drought protection. The hourly dose of equation (7) is then calculated as

$$Dh - OF \cdot [O_3] - Th, \text{ for } OF \cdot [O_3] > Th \qquad (13a)$$

and

$$Dh = 0, \text{ for } OF \cdot [O_3] < Th \qquad (13b)$$

Complete protection is achieved in the model if available soil water is low enough so that $OF \cdot [O_3] \leq Th$ throughout the day. However, previous O_3 damage is still included as a chronic effect in equation (10). The influence of drought on O_3 damage may depend on the past drought history of the crop and other factors which remain to be quantified by experimentation.

5.1.5. Estimation of Transpiration Efficiency

At present drought alone is assumed to have no effect on transpiration efficiency. This assumption is also made by Hanks and Hill (1980) who account for differential effects of the timing of drought by estimating transpiration for each crop growth stage and giving greater weight to transpiration during critical stages. (Such an approach could easily be incorporated into the present model.)

The model does allow for the possibility that O_3 affects transpiration efficiency (TE). We assume that the effect of O_3 on (TE) is proportional to its effects on seasonal transpiration ST by setting

$$(TE/TE_o) = (ST/ST')^{\gamma} \tag{14}$$

where TE and ST refer to a crop experiencing drought and O_3, TE_o is transpiration efficiency of a nonpolluted crop, and ST' is the seasonal transpiration of a nonpolluted crop which experiences the same pattern of soil moisture availability as the drought and O_3 exposed crop. The exponent, γ, determines the partitioning of O_3 effects between TE and ST. For the results which follow, O_3 is assumed to reduce seasonal transpiration and transpiration efficiency by similar percentages, i.e., $\gamma = 1$. This assumption is consistent with preliminary results for the CERL O_3 x water stress study. However, use of the more general expression in Equation (14) allows one to determine how the assumed partitioning of O_3 effects between ST and TE influences model results.

5.1.6. Preliminary Results

To illustrate the behavior of the model we assumed the average planting date and relationship between unstressed transpiration and pan evaporation reported by Haddock (1981) for midwestern soybeans. The model was run with 1978 Indianapolis O_3 data plus rainfall records from several Illinois sites to produce the O_3-response curves shown in Figure 5.1.2. Model parameters used to derive these results are listed in Table 5.1.2. Parameters β_1 and β_2 which respectively control transient and chronic modeled responses to O_3 were chosen to produce O_3-responses of the magnitude observed by NCLAN for soybeans. Although we set $\beta_1 = \beta_2$, chronic effects predominate because O_3 concentrations are integrated over a much longer time span to calculate the chronic effect. The O_3-response curves of Figure 5.1.2. were produced by increasing or decreasing O_3 proportionately across the season to vary the O_3 concentration. Thirty model runs were used to produce each curve, a process requiring 19 seconds of computer time per curve.

Figure 5.1.2. suggests that drought may significantly decrease the effect of O_3 on crop yield if the model parameters and structure are not grossly inaccurate. The impact of drought on O_3 damage is greatest for severe drought and low or moderate O_3 levels. At sufficiently high O_3 levels, the curves for crops receiving only rainfall converge with the well-watered O_3-response curve. This coalescing occurs because the O_3-exposed crops are assumed to transpire less, and at high enough seasonal O_3 levels, never experience enough drought stress to slow transpiration below that for the well-watered, high O_3 crop.

In general, the modeled yield sensivity to O_3 decreases with increasing drought severity. However, the timing of drought also has an effect on the model response. Different rainfall records producing a similar effect on seasonal transpiration may have somewhat different effects on yield sensitivity to O_3 as shown in Figure 5.1.3. Nonetheless, the model predicted some reduction in the crop sensitivity to O_3

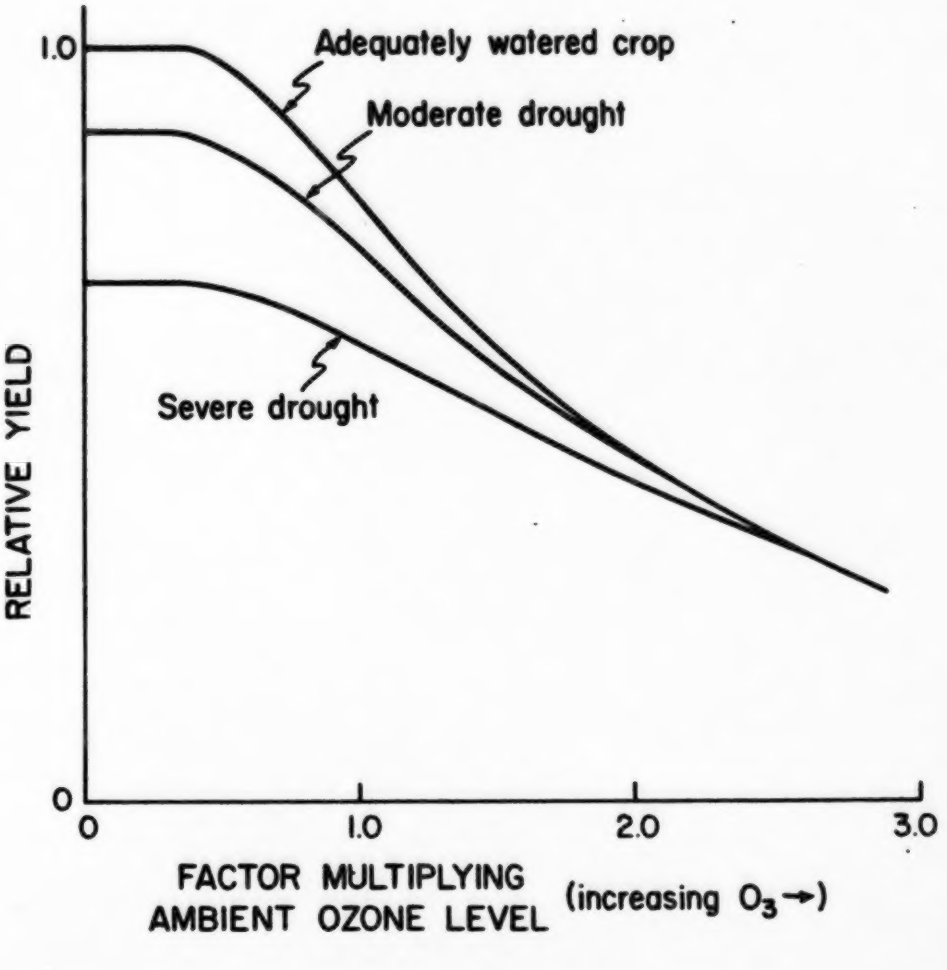


Figure 5.1.2. Example yield response to O_3 and drought.

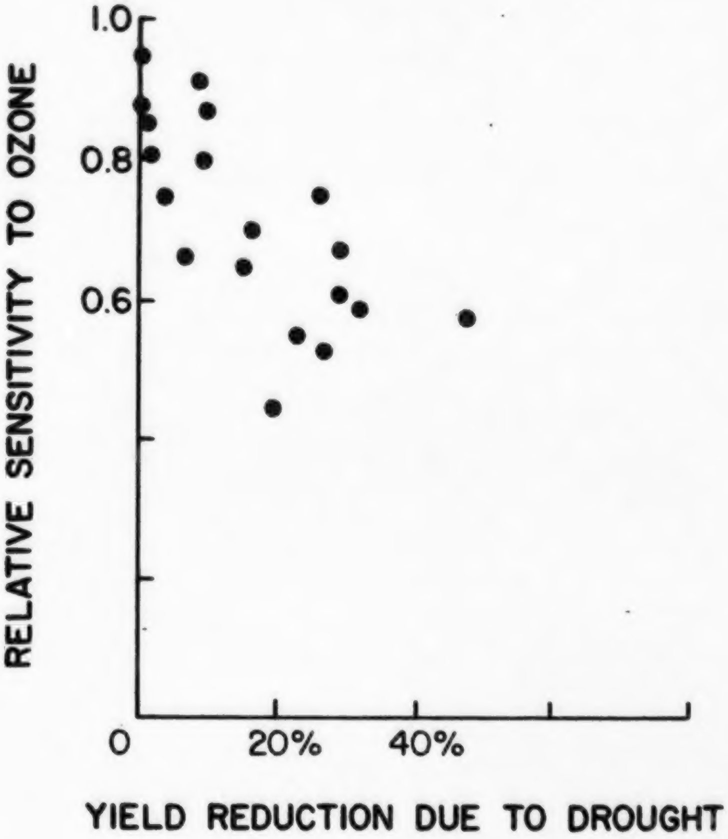


Figure 5.1.3. Relationship between drought effect on O_3 response and drought effect on yield. The relative sensitivity to O_3 was computed by choosing an O_3 level which reduced the well-watered yield by 10%. The sensitivity is then the percent O_3 effect under drought conditions divided by this 10% well-watered reduction. The points correspond to weather inputs from IL, IN, and IA.

for all of the simulations of Figure 5.1.3. (The 1978 rainfall records from Indiana, Illinois, and Iowa plus a pan evaporation record for each corresponding state were used with Indianapolis O_3 data to construct Figure 5.1.3.) It should be noted that these results are preliminary. Current analysis of the CERL on-site water stress x O_3 experiment and other NCLAN experiments may indicate interactions which are not properly accounted for in the present version of the model.

5.2. 1983 ANNUAL SUMMARY: ECONOMICS--Richard M. Adams

There were two primary objectives for 1983. These include: 1) to complete the regional economic assessments of O_3 effects on the Corn Belt and California initiated in 1982 and 2) develop and implement the national economic assessment model. The first objective was completed by the fall of 1983. Development of the national assessment model was an ongoing effort throughout 1983.

One of the secondary objectives of the regional assessments performed in 1983 was to test the feasibility of several assessment methodologies. Thus, there is no common or unique approach involved in the regional NCLAN assessments. The types of methodologies analyzed in the regional assessments include mathematical programming, econometric supply/demand analyses and a "duality" approach using econometric procedures to estimate restricted profit and production functions for Illinois grain farms. Each approach has specific analytical and practical advantages. Based on the results of the respective analyses, all are capable of providing theoretically consistent economic estimates under certain data conditions. The regional analyses were performed in the Agricultural Economics departments of the University of Illinois, the University of California, Davis, and Oregon State University. The national assessment is being performed at Oregon State University.

5.2.1. Regional Assessments

The primary purpose of each study was to empirically test the assessment methodology and/or provide estimates of regional economic effects of O_3 on agriculture. In each case, the methodology proved to be tractable in a regional context. Of particular note is the duality approach, which does not directly use externally generated dose-response data. Rather, it relies on actual producer behavior, as reflected in data on input and management practices and output levels, to record the effect of environmental stress on profits. As reported in Mjelde et al. (1984) and Garcia et al. (1985), the analysis and results seem plausible when compared with NCLAN corn and soybean results generated by Argonne National Laboratory. The other methodologies have been widely used in agricultural economic research and hence their tractability is well established. However, the Corn Belt analysis reported in McCarl et al. (1985) and Adams and McCarl (1985) have methodological significance in that they are essentially pretests of the national assessment model, given that the underlying model has national capabilities and is used as the basis for preliminary 1984 national assessment.

The empirical results of each study indicate that the magnitude of O_3 damage to agriculture may be substantial. These results are summarized in Table 5.2.1. Benefits to both consumers and producers from an

Table 5.2.1. Summary of NCLAN regional O_3 control benefits estimates

Region	Reference	Annual Benefits of O_3 Control ($ millions)	Comments
Corn Belt	Adams and McCarl (1985)	668	Uses a sectoral model of U.S. agriculture to record economic effects of changes in yields of corn, soybeans, and wheat due to alternative oxidant standards. Benefits include effects on both consumers and producers of more stringent federal standard (0.08 ppm).
Illinois	Mjelde et al. (1984)	55-200*	Uses profit functions to measure effect on producers profits. Aggregate effect over corn, soybeans, and wheat assuming a 25 percent reduction in ambient O_3.
California	Howitt et al. (1985)	37	Benefits measured as an increase in economic surplus from a reduction in ambient O_3 to 0.04 ppm seasonal 7 h. Analysis basedon a mathematical programming model of California annual crops.

*Range of economic benefits associated with a 25% reduction in O_3 from ambient levels for a 4-yr period (1978-1981).

O_3 reduction in the Corn Belt appear to be in the range of \$.6 to \$.7 billion for corn, soybeans and wheat. In California, the range of benefits across eight annual crops appears to be about \$40-\$50 million and substantially higher if perennials are included. Each of these studies is discussed in more detail below.

5.2.1.1. An application of duality to the corn belt--University of Illinois, B. L. Dixon, P. Garcia, J. W. Mjelde, R. M. Adams

This study establishes a link between production of corn and soybeans in Illinois and levels of ambient O_3. The procedure uses data collected on 229 cash grain farm operators in Illinois over the 4-year period 1978-1981. The study differs from those economic assessments that use dose response functions estimated from test plot data. Instead of ascribing the losses observed on test plots to commercial farmers, the approach is taken that farmers have in some sense accommodated the presence of O_3 in their farming techniques and thus it is possible to identify their response to O_3 levels by observing their input purchases and levels of output.

The impact of O_3 is measured by employing the so-called "dual approach" to production economics. Instead of estimating a production function directly, a profit function is estimated as a function of the price of variable inputs and the levels of fixed factors (inputs not under the control of the farmer), one of which is the level of O_3. Temperature is also considered as a fixed factor of production in the model and it is difficult to disentangle the effects of O_3 and temperature since they naturally tend to rise together. The significance of O_3 might be greater if the O_3 variable were not correlated with temperature. This problem is partially alleviated by using data from a separate study which estimates the effect of temperature on corn and soybeans. From this other study a nonsample, or prior, estimate of the temperature coefficient in the profit function is generated. Using this estimate as a stochastic restriction for the temperature coefficient in the profit function, the effect of O_3 becomes significant at the .05 level. Thus, a subsidiary finding of this study is that results from both behavioral (economic) studies and physical science studies can be combined to save the cost of extra data collection or, indeed, to help determine the effect of a given variable if it is not possible to obtain additional sample observations.

The statistical analysis of the study identifies the importance of sufficient variability of exogenous factors to estimate the impact of environmental and economic variables. The sample data show pronounced inter-year variation in the ozone data and deletion of just one year causes a loss of significance for most of the estimated parameters. Additionally, regional variation within the state appears to be important in identifying ozone effects. Future studies employing the dual approach should verify that sufficient varibility exists in the independent variables to identify the economic and environmental effects.

In agreement with purely physical science observations, ambient levels of ozone are found to decrease profit levels, implying ambient concentration levels lead to a decrease in supply. It is estimated that a 1% increase in ozone concentration over the mean concentration observed in our study (43.4 parts per billion) would lead to a .408% decrease in profits. Likewise, the estimated model shows that the levels of variable inputs purchased decline as the ambient ozone levels rise. This follows because as ozone increases, the productivity of the variable inputs decrease so the profit-maximizing farmer employs fewer of the variable inputs.

By using a simple form of the profit function and the stochastic restriction on the coefficient of temperature, a production function with ozone as an uncontrollable input is estimated. The percentage change in output, measured as an aggregate of corn, soybeans and wheat for a 1% change in ozone concentration is -.131. This is within the range of dose response estimates obtained from NCLAN experiments conducted at Argonne National Laboratory (Heck et al., 1983b). Thus, the result is obtained that two distinctly different research methods are in substantial agreement, fortifying confidence in the mutual result.

Very rough estimates of the cost of a 10% increase in ozone levels from the observed levels for the years 1979-1980 are generated. It is determined that the upper bound on costs to farmers in Illinois in terms of cash grains would have been between $92 million for 1978 to $226 million for 1980. These figures are overstated because they do not allow for the fact that the decrease in supply would elicit an increase in price which would lessen or eliminate farmer losses.

It should be emphasized that if ozone concentrations were to increase throughout the Corn Belt, supply of corn and soybeans would decrease. This would shift the supply curves to the left implying a rise in price. If the demand curves were inelastic as they tend to be, at least in the short run, prices could rise sufficiently to keep farmer profits constant so that consumers would bear the cost of increased ozone concentrations. It should be borne in mind that this study only shows the effect on producers and supply, and not on consumers. Thus, the overall cost to society is not measured. A more thorough treatment of this study is contained in Mjelde et al. (1985), Dixon et al. 1984), and Garcia et al. (1985).

5.2.1.2. A mathematical programming analysis of O_3 effects on the corn belt--Oregon State University, R. M. Adams, B. A. McCarl, S. Hamilton

Conducting economic assessments on agriculture generally requires some biological or production response data linking pollutant levels and crop yields. The relationship may be quantified directly using data generated from biological experimentation, indirectly from observed producer output and behavioral data, as attempted in the preceding duality approach or from some combination of data sources. From the standpoint of economic analysis, procedures that are based on observed producer data, such as typically used in production function estimation or dual cost function techniques, are preferred. While the duality work at the University of Illinois shows potential for such procedures at the state level, researchers in general have had little success in directly applying such techniques across large geographical areas, due to both data and statistical difficulties. As a result, national level assessments currently must rely on information from some form of biological, controlled experimentation to define the relationship between dose and plant response. The output from the NCLAN experiments is intended to provide such information. As the experiments have proceeded, discussion has ensued as to the importance of additional types of biological data (e.g., more crops or more cultivars) on any resultant economic assessment.

The purpose of this study was to provide some resolution to this issue by estimating the economic consequences of ozone on a major agricultural region under alternative sets of NCLAN data. These results are derived from a U.S. agricultural sector model (adapated from Chattin et al., 1983). Empirical emphasis is on the Corn Belt region (Illinois, Indiana, Iowa, Missouri, and Ohio), a region accounting for over 50% of U.S. corn and soybean production and 8% of wheat production. The specific objectives of the analysis are:

1) to provide assessments of the benefits of alternative secondary ambient O_3 standards to Corn Belt agriculture;

2) to test the sensitivity of benefits estimates to varying yield-response forecasts and use these results to provide insight on the importance of improved response data in benefits assessments. This latter information may be of use in the design of ongoing and future biological effects research programs aimed at environmental regulatory policy.

The economic model used to assess the effects of alternative ozone levels is a price-endogeneous mathematical programming model of the agricultural sector. Such sector models have been used extensively by agricultural economists to simulate the effect of alternative agricultural policies or technological change in agriculture (Duloy and Norton, 1973; Heady and Srivastava, 1975). Among the various methodologies available to formulate policy models, mathematical programming has proven to be a particularly useful tool, given its ability to predict potential consequence of as yet unrealized policies.

The mathematical programming model applied here consists of both a micro or producer level component and a macro component to assess aggregate effects. The features of this particular model are discussed in more detail elsewhere (McCarl et al., 1985). The sector model contains activities which represent production and consumption of various commodities. The production and consumption sectors are assumed to be made up of a large number of individuals, each of whom maximizes individual welfare function under competitive market conditions.

In this analysis, producer level behavior is portrayed by a series of linear programming representative farms ("rep-farms") for the Corn Belt region. Specifically, 12 rep-farms are modeled within the 5-state region designated as the Corn Belt by the USDA. These rep-farms are assumed to mimic the technical and economic environment of the producers in a given region. The farms are modeled with considerable detail on cropping activities (12 annual crops plus hay and beef, pork, and milk production), input use, and environmental and other fixed constraints. Such detail is needed to adequately model potential producer mitigative behavior in the face of environmental change. Production levels in the rest of the U.S. (the nine other USDA production regions) are held constant at 1980 levels.

The rep-farm or producer level responses are interfaced with the macro component of the sector model to obtain a measure of social benefits. The linking of the detailed farm level specification with a macro model measured in (changes in) consumer and producer surplus provides for a useful economic model. The use of economic surplus in policy analysis is well documented in the literature (Willig, 1976; Just et al., 1982) and is particularly relevant to agricultural uses where distributional consequences are of concern. By imposing alternative ozone levels on the rep-farm behavior, as manifested in yields predicted by the NCLAN response functions, changes in production and consumption and ultimately economic surplus between the alternative ozone levels and current ambient levels then results in benefit estimates for these alternative levels.

The steps in performing the assessment consist of: (1) developing a set of alternative O_3-yield reduction assumptions based on the NCLAN data; (2) setting up the sector model with these data; (3) solving the sector model; (4) repeating this process for the alternative solutions of interest; and (5) comparing results and drawing inferences about ozone benefit assessments and their sensitivity to data assumptions. The primary analysis focuses on a benefits assessment of ozone using best available response data. Two benefits analyses are performed using increments of response data. The first features of the set of response data in the literature prior to NCLAN (summarized in Heck et al., 1982a). The second analysis consists of selecting the most likely or reasonable set of crop response functions and ozone data from the ongoing NCLAN experiments. Criteria for selection among these latter NCLAN data are: (1) the importance of that crop variety in the state or region and (2) the statistical properties of the associated response function, including the homogeneity of response of a given cultivar vis a vis an aggregate response function using pooled data across all cultivars. Comparison of benefits estimates across each regional data set can suggest the importance of additional (and assumed more accurate) data.

The rural ambient ozone levels represent the ambient concentrations currently associated with the federal secondary standard of 0.12 ppm hourly maximum not to be exceeded more than once per year. Specifically, an assumed standard of 0.08 ppm represents an improvement in rural ozone of approximately 25% from current ambient levels, while the assumed 0.16 ppm standard portrays a degradation in ozone levels of 50% from present levels. Changes in yields predicted by the NCLAN response functions for these alternative ozone levels are then used to adjust the yields in the economic model, which is solved assuming the base model yields reflect current ozone levels. The changes in economic surplus between the base situation and the yields associated with alternative ozone levels provide an estimate of the benefits (costs) of alternative ozone levels.

The results of this analysis suggest that the benefits of imposing more stringent ozone regulations in the Corn Belt (from a peak hourly concentration of 0.12 ppm to 0.08 ppm) to be approximately $.7 billion. Conversely, relaxation in present standards from 0.12 ppm to 0.16 ppm may result in costs (negative benefits) in excess of $2.0 billion.

These estimates are based on NCLAN data through 1982. An analysis using response information prior to NCLAN (prior to 1980) estimated much lower benefits of ozone control. Assuming the site- and cultivar-specific information from NCLAN to be more accurate, the addition of these data to the assessment have important policy implications as they substantially alter the benefits estimates. Conversely, the role of additional cultivar data generated from NCLAN had a relatively minor effect on benefits estimates. For example, the range of estimates was typically less across the most extreme cultivar responses in the NCLAN data than the difference between the pre- and post-NCLAN assessments. However, additional information on ozone interactions with moisture stress and other environmental factors was found to be potentially important in improving the economic estimates. The procedures, results and caveats associated with this assessment are discussed in more detail in Adams and McCarl (1985).

5.2.1.3 Effects of alternative O_3 levels and response data on economic assessments: The case of California crops--University of California, Davis; R. E. Howitt, T. Gassard, R. M. Adams

The need for economic models that account for endogenous price effects, substitution of cropping activities, and differential impacts on producers and consumers has been well documented (Adams et al., 1982; Leung et al., 1978; Crocker, 1982). More recently, Barnes et al. (1983) criticized the O.E.C.D. methodology of cost and benefit assessment for ignoring third party effects across national boundaries and use of an inappropriate dose-response basis. This study addresses the shortcomings of some earlier economic assessments by using an economic model of California agriculture that recognizes the interdependence of cropping activities. In addition to measuring the economic effects of ozone on California's major annual crops, this study also provides some insight into the effect of alternative yield response estimates on benefit assessments. As in the preceding corn belt analyses, the differences in benefit measurements arising from use of alternative yield reduction functions can be compared. Such information can serve to guide the acquisition of response data for use in economic assessments.

Adams et al. (1982) show that a normative programming production model with endogenous price determination can be successfully used to measure the price changes associated with production changes and the effects on producers and consumers. Following Adams et al. (1982), this study uses a mathematical programming model of California agriculture, the California Agricultural Resources Model (CARM). CARM is nonlinear programming model. As such, it solves the following problem:

$$\max_{X} \; f[X] \qquad \text{such that } g[X] \leq 0 \tag{15}$$

where f[X] is a continuous function called the objective function and where g[X] is a vector of continuous functions called constraint functions. In CARM, g[X] describes the limit on available resources and the need for markets to clear (supply equals demand at some equilibrium price). In CARM, f[X] measures economic surplus (the sum of producers' surplus plus consumers' surplus) under alternative model parameters.

In this study, CARM is used to measure the impact of ozone levels on agricultural production, as reflected by the yields predicted in NCLAN response functions. Specifically, the model includes expected yields for various crops in each of 14 regions as predicted by the NCLAN response functions in combination with ambient ozone conditions. Given the ambient O_3 levels in each region, the yield effect of mandating ozone levels of 0.04, 0.05 and 0.08 ppm is entered into CARM to determine changes in cropping activities (acreage), total production, and market prices.

In an attempt to more fully account for the effect of ozone on annual crops and hence make the CARM runs more realistic, the eight crops for which response data were available (alfalfa, hay, dry beans, field corn, cotton, grain sorghum, lettuce, processing tomatoes, and irrigated wheat) were used as surrogates for other similar crops. Thus, the relative changes in yield of irrigated wheat was assumed to be an acceptable approximation for the changes for dry land wheat and for irrigated and dry land barley. Similarly, lettuce was used as a surrogate for celery and onions, processing tomatoes for fresh tomatoes and potatoes, grain sorghum for rice, and hay alfalfa for seed alfalfa. Still, this only includes the impact of O_3 on 17 of the 44 crops in CARM. To the extent that O_3 affects any of the 27 crops for which either data or a surrogate are lacking, the results from the economic model underestimate the impact of O_3 on total agricultural production. To estimate actual ambient concentrations for the base year (1978) two data sources were used: USEPA SAROAD data as modified by meteorologists at Research Triangle Park (J. Reagan, personal communication) and California Air Resource Board air quality data. These ambient concentrations are used as the base dose against which changes in yield are calculated with the estimated response functions, following the procedures outlined in Heck et al. (1984a). Finally, the crop response functions used to derive the yield depressions were selected on the basis of statistical significance and fit, and checked for consistency against prior biological information.

The results indicate that both consumers and producers are affected by changes in ozone. The monotonic decrease in consumers' and producers' surplus with increasing ozone levels means that the well-being of society diminishes with decreasing air quality. Producers of crops unaffected by ozone levels also experience losses from changes in ozone level through the effect of market forces. While the percentage changes are low, the absolute benefit of $35.7 million a year from improvements of 0.04 ppm versus costs of $157.3 million a year at the 0.08 ppm level are substantial. These benefits are consistent with those reported elsewhere for a more restricted set of crops in California and large changes in average ozone levels (Adams et al., 1982; Leung et al., 1978). The benefits and costs to producers under the 0.04 ppm and 0.08 ppm scenarios represent substantial changes in profitability: 2.3% and -10.9%, respectively, for the affected crops. Consumers of affected crops would notice gains of 0.9% and losses of 3.3% under, respectively, the 0.04 ppm and the 0.08 ppm ozone levels.

In general, as air quality improves, total production increases, price decreases, and acreage decreases, while increasing levels of O_3 tend to decrease production, increase price, and increase acreage. That acreages increase under poor air quality and decrease when quality is improved may be initially counterintuitive. However, the model is following the rational economic process of substituting land and other inputs for air quality. Quantities of water and labor show similar increases when O_3 levels increase. Thus, reduction in air quality further exacerbates the pressure on scarce land and water resources. The magnitude of the percentage changes in price, quantity and acreage vary widely across crops. These changes are determined by the interaction of the supply and demand functions and the change in relative crop profitability induced by changes in ambient ozone level through their effect on yield.

The analysis also addresses the effects of assuming alternative functional forms in the fitted regression of ozone dose response on yield. Using the ratio of the percent change in yield (between models) to the percent difference in economic estimates arising from those yields, the effects of using different response models are evaluated. This ratio is a measure of the sensitivity of the economic effects and indicates that for larger values of ozone, the effect between yield models becomes increasingly important.

For policy decisions when ozone concentrations are relatively low, the conventional statistical levels on the dose response regression coefficients can be used to derive the probability of an economic error. But where the policymaker envisages large changes in ozone level, the critical regions should be treated with more caution.

5.2.2. The Analytics of the Assessment Model

The purpose of this section is to provide a description of the economic model and procedures to be used in the 1984 preliminary national assessment. This model is a modified version of that used in the Corn Belt assessment described above. The modification of this model and the development of a set of supporting data for use in the NCLAN national ozone assessment constitute the second accomplishment of the NCLAN program in 1983. The implementation and validation of the model have also been achieved.

The analytics of the model, including the link between micro or producer behavior and aggregate measures of welfare, are discussed in some detail. This is to allow the reader to grasp the essential factors and assumptions of the model and to document the procedures that will be used in applying the model to the assessment of the national consequences of ozone. This presentation and discussion is also motivated in part by questions raised at the 1984 NCLAN peer review.

5.2.2.1. Description of the aggregate sector model

The aggregate model used in the national assessment is a mathematical programming model based on the Takayama and Judge activity analysis spatial equilibrium model, the CHAC model of Duloy and Norton (1973) as explained in Norton and Solis (1981) and the agricultural sector models of Heady and associates (as reported in Heady and Srivastava, 1975). The particular model used here was developed by Baumes (1978), improved in data specification by Burton (1982), documented in Chattin et al. (1983), updated in the Corn Belt study (Adams and McCarl, 1985) and updated again for the national assessment study. The basic model has been used in the past in other studies by USDA and the Office of Technology Assessment. It has currently been adopted for routine use by USDA (House, 1983). The revisions inherent in this current model are motivated by the methodological suggestions of McCarl (1982).

A complete description of the model is beyond the scope of this document (the reader interested in such should refer to any of the following: Chattin et al. 1983; House, 1983; Baumes, 1978; Burton, 1982). In addition, related conceptual material is given in McCarl and Spreen (1980); Norton and Solis (1981); McCarl (1982); and Heady and Srivastava(1975). Nevertheless, we will briefly cover four topics of discussion. These regard the conceptual model including all producers, aggregation to a representative set of producers with less microeconomically detailed models, the overall model structure, and calculation of economic surplus.

5.2.2.2. A conceptual model involving all producers

Conceptually, the model development starts with the farm (this development is adapted from the more detailed presentation of McCarl and Spreen, 1980): A multi-product farm is assumed to maximize its profits (income minus cost). Income arises from product price times quantity of output produced summed over all products. Cost arises from the use of purchased inputs times their prices summed over all inputs. Total farm input usage is linked to farm activity as is farm output. It is further assumed that the time dimension is long run; thus fixed factors do not exist and all inputs are priced. Under these conditions the farm's profit maximization problem may be written as:

$$
\begin{array}{lll}
\text{maximize} & -\sum_j d_j X_j + \sum_O P_O Y_O - \sum_i C_i Z_i & \\
\text{subject to} & \sum_j a_{ij} X_j \qquad - Z_i & \le 0 \text{ for all } i \\
 & -\sum_j e_{Oj} X_j + Y_O & \le 0 \text{ for all } O \\
 & \sum_j f_{mj} Y_j & \le b_m \text{ for all } m \\
 & X_j, Y_O, Z_i \ge 0 &
\end{array}
$$

where

j refers to types of farm processes

O refers to types of farm outputs

i refers to types of farm variables

m refers to types of farm fixed inputs

d_j is miscellaneouse costs employing one unit of activity X_j

a_{ij} is the use of variable input i by one unit of activity X_i

e_{Oj} is the production of output O by one unit of activity X_j

f_{mj} is the use of the farm's mth fixed inputs

b_m is the endowment of the mth fixed inputs

X_j is the number of units of farm activity j undertaken

P_O is the per unit price of the Oth output

Y_O is the number of units of the Oth output sold

C_i is the per unit price of the ith variable input

Z_i is the number of units on the ith input bought.

Given that the objective is to maximize this function then the conditions for optimality may be found through the application of the Kuhn-Tucker theorem. Thus for this problem to have an optimum we know that

1) $\frac{\partial L}{\partial x_j} = -d_j - \sum_i \lambda_i a_{ij} + \sum_O U_O e_{Oj} + \sum_m \alpha_m f_{mj} \leq 0$ for all j

2) $\frac{\partial L}{\partial Y_O} = P_O - U_O \leq 0$ for all O

3) $\frac{\partial L}{\partial Z_i} = C_i + i \leq 0$ for all i

4) $\sum_j X_j \frac{\partial L}{\partial Xj} = \underset{Y_O}{0}$

5) $\sum_O Y_O \frac{\partial L}{\partial Y_O} = 0$

6) $\sum_i Z_i \frac{\partial L}{\partial Z_i} = 0$

7) $X_j \geq 0$ for all j

8) $Y_O \geq 0$ for all O

9) $Z_i \geq 0$ for all i

10) $\lambda_i \geq 0$ for all i

11) $U_O \geq 0$ for all O

12) $\alpha_m \geq 0$ for all m

13) $\sum_j a_{ij} X_j - Z_i \leq 0$ for all i

14) $- \sum_j e_{Oj} X_j + Y_O \leq 0$ for all O

15) $\sum_j f_{mj} X_j \leq b_m$ for all m

16) $\sum_{i}(\sum_{j} a_{ij}X_j - Z_i)\lambda_i = 0$

17) $\sum_{O}(-\sum_{j} e_{Oj}X_j + Y_O)U_O = 0$

18) $\sum_{m}(\sum_{j} f_{mj}X_j - b_m)\alpha_m = 0$

Where

L is the augmented Lagrangian
U_O is the marginal value of output to the farm
λ_i is the marginal value of inputs to the farm
α is the marginal value of fixed resources to the farm.

Conditions 1, 2, and 3 above give us optimal rules for the production, sale of outputs and the use of inputs. If we assume that Y_O and Z_i are produced (i.e., > 0) then, by conditions 5 and 6, conditions 2 and 3 would be strict equalities. This leads to a solution in which the optimum value of U_O and λ_i equal the price of output and price of input, respectively. Thus, for a profit-maximizing farm, the marginal revenue from producing more of an output is price and the farm equates prices to its marginal value of output. Similarly, the marginal cost of inputs is equated to their price. Thus the conditions for production are given by substituting into 1 which becomes

$$-d_j - \sum_{i} C_i a_{ij} + \sum_{O} P_O e_{Oj} \leq 0$$

or

$$\sum_{O} P_O e_{Oj} = \sum_{i} C_i a_{ij} + d_j$$

which implies at optimality that the profit-maximizing farm produces output (X_j) until the marginal revenue of producing that output (summed price times output quantity) is less than or equal to the marginal cost of production (summed input cost times usage plus miscellaneous cost).

Given these profit-maximizing conditions for an individual farm, one can form conditions for the agricultural sector. Implicit in the above discussion is the assumption that the price of outputs and inputs are constant regardless of the level of activity by the farm. This is hardly true of the aggregate. Clearly as the quantity of a crop produced decreases then the price to consumers increases. Similarly the prices of inputs such as labor and land would be related to quantity used. Thus, it is reasonable to adopt demand and supply functions for products and inputs. Let the price of these items be a linear function of the volume produced:

$$P_O = f_O(\overline{Y}_O)$$

$$C_i = g_i(\overline{Z}_i)$$

where

$f_0(Y_0)$ is the inverse demand function of the 0th output

$\overline{Y}_0$ is total production summed across all farms

$g_i(\overline{Z}_i)$ is total use of the ith input.

Here we assume that the price of an item is dependent on own quantity only and that all other factors can be collapsed into the curve *a priori*.

Given these functions we may now write a set of first order conditions which includes the aggregate, but maintains the individual farm profit-maximizing conditions. These conditions would involve a) the addition of a subscript for farm (k) on all the parameters and variables above; b) the inclusion of equations to form the aggregates

$$\sum_k Y_{0k} - \overline{Y}_0 = 0$$

$$\sum_k Z_{ik} - \overline{Z}_i = 0;$$

c) the inclusion of aggregate dual variables $(\overline{U}_0, \lambda\overline{i})$ which equal the farm shadow prices (U_{0k}, λ_{ik}) for all farms; and d) the inclusion of a relationship between the aggregate price and the shadow price

$$f_0(\overline{Y}_0) - U_0 \leq 0$$

$$-\overline{\lambda}_i + g_i(Z_i) \leq 0.$$

These equations describe a situation under which all the firms maximize profits in a perfectly competitive agricultural sector. The conditions are duplicated by the following optimization model:

$$\text{maximize} \quad \sum_{0} \ {}_{0}^{Y_0} f_0(Y)dY + {}_{i} \ {}_{0}^{Z_i} g_i(Z)dZ$$

$$+ \sum_{k} \sum_{j(k)} d_{jk}X_{jk}$$

$$\begin{array}{llcll}
\text{Subject to:} & \sum_{j(k)} a_{ijk}X_{jk} & - & Z_{ik} & \leq 0 \text{ for all k and i} \\
 & \sum_{j(k)} a_{0jk}X_{jk} & + & Y_{0k} & \leq 0 \text{ for all k and 0} \\
 & \sum_{k} Z_{ik} & - & \overline{Z_i} & \leq 0 \text{ of all i} \\
 & \sum_{k} \overline{Y}_{0k} & - & Y_0 & \leq 0 \text{ for all 0}
\end{array}$$

$$X_{jk}, \bar{Y}_O, \bar{Z}_i, Y_{Ok}, Z_{ik} \quad 0$$

This forms the base conceptual framework underlying this assessment. (see McCarl and Spreen, 1980 for a more detailed development).

5.2.2.3. Aggregation

The above model explicitly works with individual farms. Such microeconomic detail for every farm is unrealistic in an empirical study of the scope undertaken here. Consequently, following the procedures of all previous spatial equilibrium studies we use geographically "homogeneous" producers. The assumption is adopted therefore that within each geographical region the model for the region is adequately representative of all producers in the region. Heuristically, this would occur, following the exact aggregation literature, if all producers had the same possibilities and resources, and all technical coefficients were proportional across farms [see Day (1963), Miller (1964), Paris and Rausser (1983), and Spreen and Takayama, 1980 for elaboration]. Sheehy and McAlexander (1965), and Frick and Andrews (1965) discuss procedures for minimizing bias.

However, we have yet a further aggregation difficulty concerning microecomomic detail. At a minimum there are 55 representative farm models within the national model. The Corn Belt models each could have as many as 220 constraints and 400 activities (following Brown and Pheasant, 1983). Extrapolating to all regions the farm production component could have more than 12,000 constraints and 22,000 activities. This is unrealistic given data and computer cost limitations. Consequently the decision was made to construct more aggregate microeconomic representations. This was done following the suggestions of McCarl (1982) in which crop mixes were used to specify activities. The crop mixes were generated using the representative farm models of Brown and Pheasant (1983) for the Corn Belt and historical information in combination with USDA Farm Enterprise Data System (FEDS) data for the regions outside the Corn Belt.

5.2.2.4. Model structure

The above material has presented a view of the model which does not fully document its empirical characteristics of the agricultural sector. Here we will present a summation notation representation of the model. Nevertheless, this representation is not exhaustive in that the actual empirical model has in excess of 1,200 columns and 200 rows with numerous bounds.

The model contains the following symbols and associated definitions:

Definition of Variables

X_{tr} - the t^{th} agricultural production activity in region r.

XP_t - t^{th} processing activity.

NI_p - quantity of national input p supplied.

Ψ_ℓ - domestic consumption of the ℓ^{th} primary agricultural commodity.

$\eta_{n\ell}$ - n^{th} step on the excess supply function facing the U.S. for the ℓ^{th} agricultural commodity.

Γc - domestic consumption of the c^{th} processed commodity.

γnc - n^{th} step on the excess demand curve for the c^{th} processed commodity facing the U.S.

θ_{rq} - supply of the q^{th} land type in region r.

λ_r - supply of hired labor for the r^{th} region.

$FAMLB_r$ - use of farm family labor in the r^{th} region.

Technical Coefficient Definitions

a_{tr_ℓ} - per unit yield of the ℓ^{th} agricultural commodity in the t^{th} production activity in the r^{th} region.

$a2a_{trc}$ - per unit usage of the c^{th} processed commodity in the t^{th} production activity in the r^{th} region.

h_{t_ℓ} - per unit use of the ℓ^{th} agricultural commodity in the t^{th} processing activity.

Πn_ℓ th agricultural commodity imported at the n^{th} step of the excess supply curve facing the U.S.

$a2_{tc}$ - per unit yield of the c^{th} processed commodity from the t^{th} processing activity.

$\Pi 2_{nc}$ - quantity of the c^{th} processed commodity imported at the n^{th} step on the excess supply curve facing the U.S.

kk_{n_ℓ} - quantity of the ℓ^{th} agricultural commodity exported at the n^{th} step on the excess demand curve facing the U.S.

ww_{nc} - quantity of the c^{th} processed commodity exported at the n^{th} step of the excess demand curve facing the U.S.

lb_{tr} - per unit use of agricultural labor in the t^{th} agricultural production activity for the r^{th} region.

ln_{trq} - quantity of the q^{th} land type used per unit of the t^{th} production activity in the r^{th} region.

lnS_{tsqr} - quantity of the q^{th} land type used in the S^{th} state by X_{tr}.

I_{trp} - per unit use of the p^{th} national input in the tth agricultural production activity in region r.

$NI2_{tp}$ - per unit use of the p^{th} national input in the t^{th} processing production activity.

d_{trj} - per unit use of the j^{th} agricultural production regulation by the t^{th} production activity in the r^{th} region.

$d2_{tw}$ - per unit use of the w^{th} processing regulation by the t^{th} processing activity.

$d3_{ps}$ - per unit use of the s^{th} input regulation by the p^{th} national input.

$d4_{qrs}$ - per unit use of the s^{th} input regulation by the q^{th} land type in the r^{th} region.

$d5_{rs}$ - per unit use of the s^{th} input regulation by agricultural labor in the r^{th} region.

Objective Function Cost Coefficients

b_{tr} - per unit cost of the t^{th} agricultural production activity in the r^{th} region.

$q_r(\lambda_r)$ - area generating function for labor supply curve for the r^{th} region at quantity λ_r.

$h_{rq}(\theta_{rq})$ - area generating function for land supply of the q^{th} type in the r^{th} region.

z_p - cost of supplying one unit of the p^{th} national input.

g_t - per unit cost of the t^{th} processing production activity.

$dd_{n\ell}$ - area under the excess supply curve facing the U.S. for the ℓ^{th} agricultural commodity up to the n^{th} step.

xx_{nc} - area under the excess supply curve facing the U.S. for the c^{th} processed commodity up to the n^{th} step.

bb_{ℓ} - area generating function for the domestic demand curve for the ℓth agricultural commodity.

rw_r - reservation wage for farm family labor in the r^{th} region.

$gg_c(\Gamma_c)$ - area generating function under the domestic demand curve facing the U.S. for the c^{th} processed commodity.

$mm_{n\ell}$ - area under the excess demand curve facing the U.S. for the ℓth agricultural commodity up to the n^{th} step.

yy_{nc} - area under the excess demand curve facing the U.S. for the c^{th} processed commodity up to the n^{th} step.

Right Hand Side Definitions

ccc_r - quantity of farm family labor in the r^{th} region.

ddd_{qr} - initial land endowment of the q^{th} type in the r^{th} region.

eee_s - maximum land use in state s.

fff_p - initial stock of national input p.

The formal linear programming model is given below.

Agricultural Commodity - Marketing Clearing

$$(1) \quad -\sum_{t=1}^{T_1} \sum_{r=1}^{R} a_{tr_\ell} X_{tr} + \sum_{t=1}^{T_2} h_{t\ell} XP_t - \sum_{n=1}^{N} \Pi_{n\ell} \alpha_{n\ell} + + \sum_{n=1} kk_{n_\ell} \eta n_\ell \leq 0$$

$= 1, 2, \ldots L$

Equation (1) states that production of the t^{th} agricultural commodities by all technologies employed in all regions less the total quantity demanded as inputs by the processing sector, plus imports of the commodity, less domestic consumption, less foreign demand or exports, must be greater than or equal to zero. Or, more simply stated, quantity supplied is greater than or equal to quantity demanded.

Secondary Commodity - Market Clearing

$$(2) \quad -\sum_{t=1}^{T_2} a2_{tc} XP_t - \sum_{n=1}^{N} \cdot \Pi 2_{nc} T_{nc} + \Gamma_c + \sum_{n=1}^{N} ww_{nc} \Upsilon_{nc} + \sum_{t=1}^{T_1} \sum_{r=1}^{R} a2a_{trc} X_{tr} \leq 0$$

$c = 1, 2, \ldots, C$

Equation (2) is the same relationship as equation (1), except it refers to processed commodities. Production plus imports, less domestic demand, less exports, is greater than or equal to zero.

Regional Agricultural Labor - Market Clearing

$$(3) \quad FAMBL_r + \sum_{t=1}^{T_1} lb_{tr}X_{tr} - \lambda_r - ccc_r \leq 0$$

This equation represents the supply and demand interaction in the agricultural labor market by region. The amount of labor demanded by all technologies must be less than the hired labor supplied plus the family labor used, where family labor used must not exceed the stock of family labor.

Agricultural Land - Marketing Clearing

$$(4) \quad \sum_{t=1}^{T_1} ln_{trq}X_{tr} - \theta_{rq} - ddd_{qr} \leq 0$$

$q = 1, 2, \ldots, Q \quad r = 1, 2, \ldots, R$

The land required by each technology or production activity employed cannot exceed the land supplied in the region.

$$(5) \quad \sum_{t=1}^{T_1} gn^{S}_{tsqr} X_{tr} - eee_{sq} \leq 0$$

$s = 1, 2, \ldots, NS$

The land required in a state cannot exceed the maximum tillable acres.

National Inputs - Market Clearing

$$(6) \quad \sum_{t=1}^{T_1} \sum_{r=1}^{R} I_{trp}X_{tr} + \sum_{t=1}^{T_2} NI2_{tp}XP_t - NI_p - fff_p \leq 0$$

Equation (6) introduces the interrelationship between the processing and agricultural sector. The use of national inputs in all of agriculture plus the use of national inputs in processing must be less than the quantity purchased plus the quantity already owned.

Foreign Demand - Agricultural Commodities

$$(7) \quad \sum_{n=1}^{N} \eta_{n_\ell} \leq 1 \qquad = 1, 2, \ldots, L$$

Foreign Demand - Processed Commodities

$$(8) \quad \sum_{n=1}^{N} \gamma_{nc} \leq 1 \qquad c = 1, 2, \ldots, c$$

Equations (7) and (8) are constraints to insure that a convex combination of adjacent linear segments on the specified price responsive supply (factors) and demand (outputs) curves are chosen in solution following Duloy and Norton (1973).

Objective Function

maximize

$$(9) \quad - \sum_{t=1}^{T} \sum_{r=1}^{R} b_{tr} X_{tr} - \sum_{r=1}^{R} q_r(\lambda_r) - \sum_{r=1}^{R} \sum_{q=1}^{Q} h_{rq}(\theta_{rq})$$

$$- \sum_{p=1}^{P} z_p NI_p - \sum_{t=1}^{T2} g_t XP_t$$

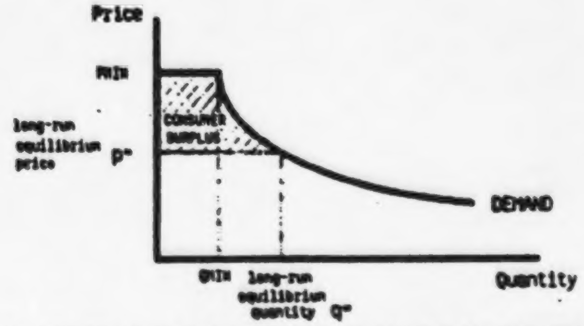
$$- \sum_{c=1}^{C} gg_c(\Gamma_c) + \sum_{\ell=1}^{L} \sum_{n=1}^{N} mm_n \eta_{n_\ell}$$

$$+ \sum_{c=1}^{C} \sum_{n=1}^{N} yy_{nc} \gamma_{nc} + \sum_{\ell=1}^{L} \sum_{n=1}^{N} rw_r FAMLB_r$$

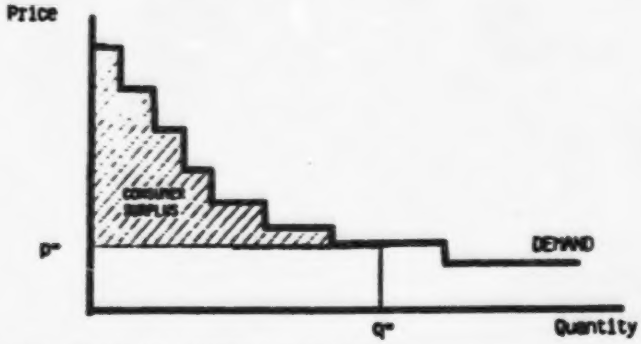
Equation (9) is the total sum of producer's plus consumer's surpluses realized for all markets; factor market and output or product market.

When given the appropriate technical coefficients, objective function cost coefficients and right hand side values, the maximization of equation (9) subject to constraints (1) - (8) leads to a competitive equilibrium. Equilibrium price and quantity levels for factors of production, agricultural and nonagricultural commodities are determined endogenously subject to the constraints imposed on the model.

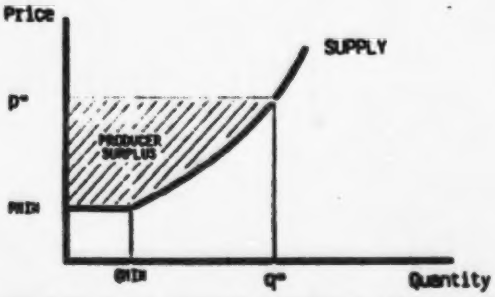
The area generating functions are formed as follows. The curves are basically either infinitely or finitely elastic. The infinite elasticity cases for some inputs reflect a constant price (times quantity). The finite elasticity curves for outputs are put in as a kinked curve, which is infinitely elastic to a point, then display a constant elasticity (to avoid unrealistic solutions and enhance analytical tractability). The join point occurs at a different point for supply and demand curves. The floor price for supply curves is the price which is the larger of one-third the 1980 equilibrium price or the price which would generate one-third the 1980 equilibrium quantity on the constant elasticity curve which would pass through the 1980 equilibrium price and quantity. The ceiling price for the demand curve is the smaller of three times the 1980 price or that price which would generate one-third the 1980 quantity. Thus, the area under these curves is calculated as in the attached figures (Figures 5.2.2.1a, 5.2.2.1b and 5.2.2.1c). The term PMIN is the floor or ceiling price. The area to that point is PMIN times quantity; the additional area from the intersection of PMIN and the constant elasticity curve is calculated by integration.


Price
PMIN
long-run
equilibrium
price
P*
CONSUMER
SURPLUS
DEMAND
QMIN
long-run
equilibrium
quantity Q*
Quantity

(1a) CONSUMER SURPLUS FOR MODIFIED CONSTANT ELASTICITY DEMAND CURVE


Price
CONSUMER
SURPLUS
P*
DEMAND
Q*
Quantity

(1b) CONSUMER SURPLUS FOR STEPPED DEMAND CURVE


Price
SUPPLY
P*
PRODUCER
SURPLUS
PMIN
QMIN
Q*
Quantity

(1c) PRODUCER SURPLUS FOR MODIFIED CONSTANT ELASTICITY SUPPLY CURVE

Figure 5.2.2.1. Calculation of economic surplus

The reader should note that the product supply functions implicit within this model are not constant elasticity but rather are curves which are projected through the production process.

As with any attempt to model a complex system, the mathematical model above has its limitations. The first of these is the assumed independency of the factor supply and product demand schedules. The cross price effects for supply (of inputs) and demand (for outputs) is omitted. Secondly, the influence of income generated as a demand shifter has been omitted. Thus, demand curves supplied to the model may over or under estimate the true demand if income is different than the base year.

5.2.2.5. Welfare measures: Economic surplus

The objective function of the sector model is used to obtain measures of social benefits from changes in air quality. The sector model features demand relationships for sectoral outputs (commodities) of various types. The elasticity and equation forms vary with end use; export demand is elastic. Assuming supply and demand functions which are integrable and independent of sector activity, first order conditions are then met in the sector model specification. The objective function of this specification is empirically specified on equation (9) but can be conceptually represented as

$$\text{maximize} \quad \Pi = \sum_{i} g_i(Z_i) - \sum_{j} e_j(X_j) - \sum_{m} c_m Y_m$$

where Π is the sum of ordinary consumers' and producers' surplus and the integrals are evaluated from zero to Z_i^*, the amount of i^{th} commodity produced and sold to consumers; and from zero to X_j^*, the amount of the j^{th} factor used. The parameters are as follows:

$g_i(Zi)$ is the area under the demand function for the i^{th} product;
$e_j(Xi)$ is the area under the supply function for the j^{th} factor;
$cm(Ym)$ is the miscellaneous cost of production;

subject to the technical and behavioral constraints defined above. Given the micro and macro structure of a model, the sector model solution then simulates a long-run, perfectly competitive equilibrium.

Following Samuelson (1952), the objective function may be interpreted as a measure of ordinary consumers' and producers' surplus (quasi-rents) or net social benefit. Analytically, this is defined as the area between the demand and supply curves to the left of their intersection. The demand functions are specified at the national level, as are aggregate production responses. The producer quasi-rents are measured through the factor markets (land and labor). The use of these measures has been demonstrated in Just et al. (1981) and Just and Hueth (1980) to be analogous to measurement of producers surplus through the aggregate supply function. Justification for the use of economic surplus in policy analysis is well documented in the literature (Willig, 1976; Just et al., 1981) and is particularly relevant to agricultural uses where distributional consequences are of concern. By imposing alternative ozone levels on the producer behavior, as manifested in yields predicted by the NCLAN response functions, changes in production and consumption and ultimately economic surplus may be measured. Comparisons of changes in surplus between the alternative ozone levels and current ambient concentrations indicates the benefits for these alternative ozone levels.

The mechanics for calculating producer and consumer surplus is a straightforward application of integration and optimization procedures. The mathematical program used to solve the sector model calculates the value of the nonlinear objective function. This objective function is calculated by integrating the area under the demand curves less the area under the supply curves less other costs.

In the model, demand curves are of three main types: constant elasticity, perfectly elastic, and step-like curves. The consumer surplus is calculated as the area between the demand curve and price line. However, the area below a constant elasticity demand curve and above the price line does not sum to a limit. Consequently, the constant elasticity demand curves have been truncated at a level equal to one-third the initial equilibrium price, or one-third the initial equilibrium quantity, whichever is associated with the smaller quantity. The truncated demand curve is then joined to a perfectly elastic demand curve at that level (see Figure 5.2.2.1).

Supply curves for land and labor are also of the constant elasticity type. A similar truncation occurs for these curves since it is unrealistic to expect these curves to pass through the origin. The producer surplus is calculated by commodity. However, producer and consumer surplus can also accrue when a production or consumption constraint is active. In this case, there will be an addition to the surplus as measured by the area below the price line and above the supply curve if an upper limit on production is reached, or a subtraction from that area if a lower limit is active. This area is calculated by multiplying the constraint shadow price times its right-hand side. No constraints on consumption were imposed in the model.

Thus, only two deviations from the standard calculation of consumer and producer surplus occurred. The first related to the modification of constant elasticity supply and demand curves. The second deviation incorporated the welfare effect of constraints on production.

5.2.3. Assessment Procedure

The economic model, in combination with yield changes predicted by the NCLAN response functions for each ozone assumption, is used to generate estimates of economic effects due to ozone changes. Each of a series of hypothetical ozone scenarios is judged against a base case analysis. The difference between economic surplus in the base case solution and the hypothetical ozone analyses represents the benefits or costs (negative benefits) of the ozone change. The base case is intended to reflect 1980 actual agronomic, meteorological and economic conditions, i.e., the base case analysis is one where the economic model is run (solved) using 1980 actual parameters, including yields. The credibility of the base model solution is established by comparing the predicted values of key variables, such as equilibrium prices and farm revenues with actual values for the base year. Establishment of a close correspondence between model output and actual values is needed to confirm the general validity of the model.

Once a plausible solution is established for a base case, the model is then solved using alternative yield values (modified from actual 1980 yields) that reflect hypothetical ozone levels in each production area (state or sub-state levels). The yield adjustments are derived by use of an appropriate mix of NCLAN response functions with the respective hypothetical ozone levels. In the preliminary national assessment four alternative ozone levels are evaluated: a 10%, 25%, and 40% reduction in ambient ozone concentrations and a 25 percent increase in ozone (from 1980 and 1978-82 mean levels).

Following NCLAN protocols, a Weibull density model specification of the relationship between ozone and yields is adopted. Among the set of functional forms tested by NCLAN, the Weibull has been selected as the most reasonable (and flexible), based on biological and statistical considerations (Rawlings and Cure, 1985; Heck et al., 1983b). Within this functional form, however, there are still eleven cultivars of soybeans, four of corn, eight of wheat, and two of cotton from which to choose, as well as individual cultivars for grain sorghum and barley.

Initial screening of these cultivar responses with the Weibull model indicates that a common or "pooled" response for soybeans, wheat, and corn, estimated using data from multiple cultivars of a given crop may be appropriate, given the statistically homogeneous proportionate response displayed by most cultivars. Thus, the pooled Weibull response models for corn, soybeans and wheat, in combination with Weibull models for irrigated (western U.S.) and non-irrigated (southeast) cotton cultivars and the individual cultivars for grain sorghum and barley constitute one possible cultivar mix. Using this set of response functions, the four ozone alternatives are then translated into corresponding yield changes. The economic effects of these four yield change situations are evaluated with four corresponding model solutions. This set of four evaluations constitute Analysis I. Through the use of the pooled data, this analysis incorporates nearly all the response information available from four years of NCLAN experiments.

The use of a pooled response for soybeans, corn, and wheat is based on the statistical homogeneity of response (proportionate) across the set of cultivars for each crop. However, this does not imply that the cultivars predict identical yield changes for the same ozone level. Also, within a given crop, a few cultivars were shown to be non-homogeneous. For example, of the eight soybean cultivars, two are not statistically homogeneous. Thus, it is possible that at the regional level, some subset of these individual cultivars may more accurately predict yield response. To cover this possibility, a second general analysis is performed, where more region-specific cultivar responses are used. This next set of four ozone-yield solutions is identified as Analysis II.

Analyses I and II use various combinations of pooled responses for certain crops. In the pooled analyses, a few cultivars are ignored because of their heterogeneous nature. However plausible it may be to view these as atypical responses, it is nonetheless possible that their response may characterize some regional response patterns. An analysis based on these more extreme responses can also serve to place some bounds on the assumed "more representative" responses captured in Analyses I and II. Analysis III thus uses the single cultivars available for barley and sorghum in combination with the most sensitive non-heterogeneous cultivars of corn, soybeans, wheat and cotton.

The assessment procedure also requires use of a base ozone level in the calculation of yield changes. Since the economic model is calibrated to 1980, 1980 ozone levels are a logical benchmark for use in the hypothetical ozone analyses. These 1980 values underlie Analyses I, II and III. However, annual variations in seasonal ozone levels is quite high for some areas, amounting to annual variation of as much as 40% in some cases. To smooth out some of this variability and ease the problems of using a given or "representative" year, alternative base years (from 1978 to 1982) are averaged and the average values are used as a second characterization of base ozone levels. These new ambient ozone levels for each region are then used to evaluate the four ozone situations, i.e., the 10, 25, and 40 % changes are now calculated relative to the alternative ozone base level. The response functions used in the evaluation are those for the first analysis (the national pooled responses). This set of four model solutions or runs is identified as Analysis IV.

The pairing of a detailed economic model and the full set of NCLAN data is intended to provide economic estimates of ozone effects occurring under "real world" conditions. However, the NCLAN data do not deal with interactions between ozone effects as manifested in the field chambers and other environmental stress factors. For example, the presence of drought or moisture stress within individual NCLAN field plots has been shown to reduce the effects of ozone on crop yields. Thus, it is possible that if plants are drought-stressed during high ozone levels, the effects of ozone, as predicted by controlled experiments when plants are typically well-watered, may overstate the effects of ozone. This possibility has important implications in a national assessment, where from 50 to 90% of the acreage of major crops are grown under non-irrigated conditions. Even if drought is not identified as a major meteorological event in a given growing season, non-irrigated crops probably still experience less than optimal moisture conditions at some point in the growing season.

Limited data are available on ozone-water stress interactions from three NCLAN experiments, one on cotton and two on soybeans. In addition, an NCLAN yield-moisture stress model also provides some information on the effect of water stress on yields and indirectly on ozone effects. The results of these studies can be used to provide some crude quantitative adjustments to the fully watered response functions generated from NCLAN data. Using these limited observations, the fifth general analysis (Analysis V) examines the effect of ozone on crops in the presence of water stress. The cultivar mix again is that used in the first analysis (pooled or common response using 1980 ozone levels).

These five analyses, in combination with the four ozone levels and the base case, result in 21 distinct economic assessments (model solutions) using the farm level-sectoral model formulation. The general assumptions underlying the five analyses are summarized in Table 5.2.3.1. Analyses II through V can be viewed as analyses of the sensitivity of the economic

Table 5.2.3.1. Summary of alternative assessment analyses: Cultivar, O_3 and stress assumptions

Analysis	Cultivar Mix	Ambient Ozone	Moisture Stress	Evaluation
I	Pooled response of all homogeneous cultivars for soybeans, corn, wheat, cotton; individual cultivars for barley and sorghum	1980 Seasonal Average	Not Treated	Pooled analysis based on all homogeneous cultivars. This analysis is intended to minimize extrapolation bias between sites and broad-scale assessments.
II	"Regionalized" pooled response for homogeneous cultivars of soybeans, corn, wheat and cotton. Individual cultivars for barley and sorghum.	1980 Seasonal Average	Not Treated	Analysis based on pooled data for homogeneous cultivars common to a given region.
III	Individual cultivars for all crops. Cultivars for corn, wheat, soybeans and cotton represent extreme yield effects in NCLAN data set.	1980 Seasonal Average	Not Treated	Extreme analysis to test the sensitivity of the economic estimates to the maximum variability in cultivar response information.
IV	Same as found in Analysis I	Average of 1978-1982 Seasonal Average	Not Treated	Analysis is to test the effect of ozone year(s) on estimates. Smooths out variability in annual ozone levels.
V	Same as found in Analysis I	Same as Analysis I	Adjusted on basis of NCLAN moisture stress experiments and crop yield moisture stress model and 1980 rainfall.	Preliminary attempt to adjust for moisture stress. Can serve to suggest possible bias in analysis that ignore other stress factors.

estimates to varying yield assumptions. To implement these analyses, considerable data, both from the NCLAN field experiments and the air quality and meteorological programs, are needed. These data sets and modifications, where required, are discussed in detail in the following section.

5.2.4. The Data: Sources and Assumptions

Implementing the economic model and performing the five analyses requires biological and meteorological information. This section discusses the sources of these data and assumptions inherent in their use.

5.2.4.1. Plant response

A major goal of the NCLAN program is to develop a base of plant science information on the response of crops to ozone and other stresses. Currently, these published data cover four years of crop experiments (1980-1983), conducted on multiple crops and cultivars at five sites in the U.S. The procedures and results of these analyses have been well documented in journal articles and annual reports prepared by the NCLAN Research Management Committee and the individual researchers (e.g., see Heck et al. 1982a; 1982b; Heck et al. 1983a; Heck et al. 1983b). In addition, Heck et al. (1984b) summarize the cumulative response information, in dose-response form, for the four years of the program. This summary publication is the source of the individual crop response functions used in the preliminary national economic assessment.

The response functions reported in Heck et al. (1984b) encompass both individual cultivars for each of the six crops and a set of common or "pooled" responses for each crop using multiple cultivars. The pooled responses are estimated using data from sets of cultivars demonstrated to be statistically homogeneous (display the same proportionate response). Such pooling is one means by which the potential variability across individual sites can be tested. If responses generated at different geographical locations are deemed statistically homogeneous, then some of the acknowledged problems of extrapolation from specific sites to broader regional scales can be minimized. For some crops (barley and sorghum) only one cultivar has been tested and hence a pooled response is not possible.

The response functions (from Heck et al., 1983b, 1984b) that are used in this assessment are summarized in Table 5.2.4.1. Note that all functions are reported in the Weibull form. The Weibull functions reported in Table 5.2.4.1 are used to project ozone-induced yield adjustments for each crop under the various analyses contained in the economic assessment.

The common or pooled responses, in combinations with the single cultivar data available for barley and sorghum, are used to develop the first set of crop yield adjustments for use in Analysis I. Then, the more "regionalized" pooled response functions estimated from subsets of cultivars, in combination with the single cultivar crops, are used to develop the yield adjustments in a second general analysis (Analysis II). By using the cultivar combinations showing statistically homogeneous response patterns, Analysis I and II are intended to minimize problems of extrapolation from data generated at specific sites to large scale regional effects. Finally, a set of response functions composed of individual

Table 5.2.4.1. Weibull model parameter estimates, by crop and cultivar combinations*,**

Crop/Cultivar	Parameters			Degrees of Freedom	Residual Mean Squares
	α	σ	c		
Barley (Poco cv.)	1.988 (0.051)a/	0.205 (0.669)	4.278 (17.15)	21	0.0248
Corn (Pioneer-3780 cv.)	12533 (323)	0.155 (0.004)	3.091 (0.461)	17	774833
Corn (2 pooled cultivars)b/	--	0.158	3.530	--	--
Cotton (Acala SJ-2 cv.)	5351 (310)	0.092 (0.005)	2.530 (0.731)	21	422162
Cotton (Stoneville-213 cv.)	3686 (140)	0.112 (0.004)	2.577 (0.416)	21	52171
Cotton (2 pooled cultivars)c/	--	0.226	1.445	--	--
Grain Sorghum (Dekalb-28 cv.)	8137 (218)	0.296 (0.019)	2.217 (1.229)	17	195875
Soybeans (Davis cv.-1981)	5593 (863)	0.128 (0.019)	0.872 (0.284)	43	91452
Soybeans (all data) (16 pooled cultivars)d/	--	0.165	1.303	--	--
Soybeans (Corn Belt) (5 pooled cultivars)e/	--	0.144	1.307	--	--
Soybeans (Southeast) (5 pooled cultivars)f/	--	0.144	1.576	--	--

Table 5.2.4.1. Continued

Crop/Cultivar	Parameters			Degrees of Freedom	Residual Mean Squares
	α	σ	c		
Wheat, winter (Roland cv.)	5479 (312)	0.113 (0.005)	1.633 (0.288)	17	91726
Wheat, winter (2 pooled cultivars)g/	--	0.146	2.235	--	--
Wheat, spring (4 pooled cultivars)h/	4.480 (0.200)	0.186 (0.040)	3.200 (1.860)	--	--

*The general form of the Weibull model is:

$$y = \alpha \exp [- x/\sigma^{c}] + \Sigma$$

where y is yield and x is the O_3 dose in seasonal 7-h/da mean concentration in ppm. The parameters are α , the hypothetical maximum yield at zero ozone concentration; σ , the ozone concentration when yield is 0.37 σ; c, a dimensionless shape parameter (e.g., c=1 is the exponential loss function and larger c's imply less response).

**Special notes are shown with following superscripts:

a/Values in parentheses are standard errors.

b/Includes Pioneer 3780 and PAG 397 cultivars.

c/Includes Acala SJ-2, irrigated and dry cultivar experiments.

d/Includes Amsoy, Corsoy 1980, 1983; Davis 1982, 1983; Essex, Forrest 1982, 1983, irrigated and dry cultivar experiments.

e/ Includes Amsoy, Corsoy 1980, 1983(2) and Hodgson cultivar experiments.

Table 5.2.4.1. Continued

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[f] Includes Davis 1982, 1983; Essex and Forrest 1981, 1983(2) cultivar experiments.

[g] Includes Abe and Arthur 71 cultivars.

[h] Includes Blueboy II; Coker 47-27; Holly and Oasis cultivars.

SOURCE: Heck et al., 1984b, Tables 1 and 3; and Heck et al. 1983, Table 2. Response functions incorporating 1983 data (the pooled soybean models) are from W.W. Cure (personal communication).

cultivars that are not statistically homogeneous in response (as compared with the cultivars in the "pooled" response analyses) are used to predict yields. These responses are representative of the most extreme response possibilities for each crop. This set constitutes Analysis III.

5.2.4.2. Air quality

To utilize the NCLAN response functions, two types of air quality data are needed. First, some measures of actual ambient ozone concentrations in rural production areas are necessary as a starting point. These ozone data must be in a dose-measure consistent with that used in the NCLAN experiments (seasonal 7-h concentration) at a geographical scale sufficient to be compatible with the 55 production regions in the sectoral model. Ideally, actual monitored data for all agricultural production areas in the economic model should be used. Unfortunately, such complete data do not exist, as the best available data (from USEPA's SAROAD system) are taken from predominantly urban monitors. However, a surrogate data set has been prepared and is commonly referred to as the "Reagan" data (J. Reagan, U.S. EPA, RTP, personal communication). The procedures and county level results giving rise to this data set for five years (five growing seasons encompassing April through September measurements) covering the period 1978-1982 are discussed elsewhere (Heck et al., 1983a, pp. 198-219).

The surrogate county-level ambient ozone concentrations are derived by a spatial interpolation of the USEPA SAROAD monitoring data. This interpolation between monitoring sites is based on a "Kriging" procedure that implicitly gives greater weight to nearest monitoring sites (Heck et al. 1983a, pp. 198-219). It should be noted that some states have as few as three monitoring sites. Even where sites are more numerous (over 100 in California, for example), most tend to be in urban or suburban areas. Thus, this geographical interpolation of the national SAROAD data set is subject to some uncertainties. These potential sources of error are summarized in Heck et al. (1983a). However, certain meteorological aspects of ozone make this pollutant amenable to interpolation procedures; e.g., its pervasive nature and the existence of smooth gradients of concentrations rather than abrupt spikes or plumes. Further, the nature of the dose measure (seasonal 7-h average) is also assumed to "smooth" out some of the variability in the ozone events. While these characteristics perhaps make this procedure a defensible approach to fill in gaps in the rural ambient air quality data, its use is based ultimately on the absence of any better data. The resulting state level estimates of seasonal 7-h ambient ozone data for each year and for the period 1978-1982 are presented in Table 5.2.4.2. A broad regional breakdown of these data with annual variability is presented graphically in Figure 5.2.4.1.

The Kriged O_3 concentrations for 1980 are used as the base ozone levels in Analyses I, II, and III. As an alternative base ozone assumption, the 1978-1982 average reported in Table 5.2.4.2 is used with the cultivar mix identified in Analysis I. This new base ozone-cultivar mix pairing is Analysis IV. Other annual ozone levels (from the 1978-1982 period) could have also been used to test the effect of base ozone assumptions on economic estimates. The average level was used because there was no consistent trend or pattern in the annual ozone levels when expressed at a state level. Thus, some regions displayed highest ozone levels (for the 5-year period) in years when other regions were below the 5-year average.

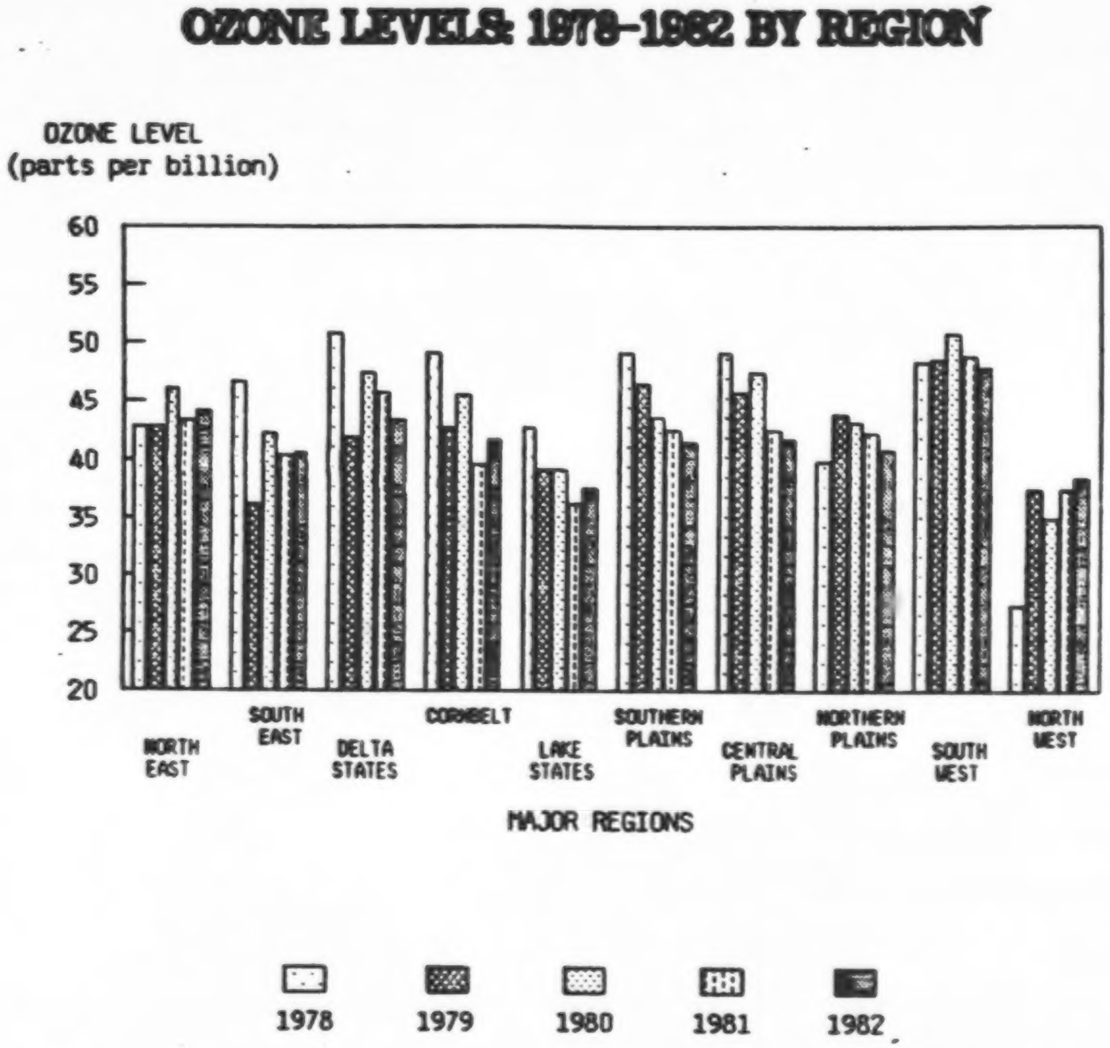

Figure 5.2.4.1. Ozone, simple average of simulated state averages; averaging time is 0900 through 1600 hours (standard time), April through September.

Table 5.2.4.2. Seasonal mean O_3 concentrations by state, 1978-1982*,**

Year State	1978	1979	1980	1981	1982	1978-1982 Average
	(parts per billion)					
Alabama	50.47	41.22	46.98	47.28	50.43	47.3
Arizona	45.62	42.48	51.63	47.93	46.07	46.7
Arkansas	56.62	50.14	51.47	47.62	45.56	50.3
California	46.82	51.14	52.04	50.44	46.29	49.3
Colorado	50.36	51.32	50.92	48.10	50.42	50.2
Connecticut	45.50	49.50	58.83	51.00	51.33	51.2
Delaware	43.00	45.00	36.00	54.00	49.00	45.4
Florida	42.98	34.69	35.33	42.51	38.87	38.9
Georgia	54.65	43.40	46.82	45.87	45.65	47.3
Idaho	N.A.	51.00	45.71	47.60	47.88	38.4
Illinois	49.92	45.30	46.92	41.69	45.52	45.9
Indiana	48.58	39.87	46.72	45.10	47.33	45.5
Iowa	47.25	40.72	42.11	32.88	35.34	39.7
Kansas	47.53	43.76	45.47	40.98	41.62	43.9
Kentucky	48.73	39.10	44.88	39.16	45.68	43.5
Louisiana	43.25	35.14	42.22	41.94	39.78	40.5
Maine	42.82	37.66	34.98	31.41	35.57	36.5
Maryland	44.91	41.82	48.72	49.73	50.73	47.2
Massachusetts	41.23	44.17	46.83	44.92	44.25	44.3
Michigan	38.05	35.60	37.56	37.93	39.40	37.7
Minnesota	43.98	36.49	39.25	32.79	33.92	37.3
Mississippi	52.35	40.50	49.25	47.20	44.38	46.7

Table 5.2.4.2. Continued

Year State	1978	1979	1980	1981	1982	1978-1982 Average
	------------------ (parts per billion) ----------------					
Missouri	52.55	48.51	49.20	37.78	40.24	45.7
Montana	34.00	49.43	45.00	46.00	46.17	44.1
Nebraska	49.03	42.30	45.17	38.10	33.45	41.6
Nevada	49.47	53.31	50.84	48.21	48.53	50.1
New Hampshire	42.25	40.75	42.58	34.58	37.50	39.5
New Jersey	42.10	43.60	53.50	50.30	51.30	48.2
New Mexico	49.96	47.90	45.87	48.40	47.02	47.8
New York	42.13	40.05	40.91	37.14	36.74	39.4
North Carolina	50.83	40.81	54.66	47.94	46.10	49.7
North Dakota	37.00	36.00	38.20	37.25	34.21	36.5
Ohio	45.98	38.42	42.77	41.04	43.88	42.4
Oklahoma	52.37	48.53	47.44	46.54	44.40	47.9
Oregon	27.32	30.11	32.06	35.20	38.18	32.6
Pennsylvania	43.65	38.31	45.11	38.20	40.85	41.2
Rhode Island	41.33	47.00	53.33	51.66	50.67	48.8
South Carolina	63.52	46.50	53.91	49.10	48.33	52.3
South Dakota	42.27	38.74	42.00	37.38	33.39	38.8
Tennessee	50.32	35.27	46.66	43.22	48.12	44.7
Texas	42.23	46.16	42.86	43.64	45.57	44.1
Utah	49.05	48.39	52.96	49.90	52.40	50.5
Vermont	43.07	42.86	43.14	35.36	37.29	40.3

Table 5.2.4.2. Continued

State \ Year	1978	1979	1980	1981	1982	1978-1982 Average
	(parts per billion)					
Virginia	52.90	40.71	54.80	48.16	49.33	49.2
Washington	27.63	31.34	26.49	28.78	28.65	28.6
West Virginia	41.77	37.91	44.14	39.05	41.10	40.8
Wisconsin	45.81	43.59	40.46	38.19	38.55	41.3
Wyoming	46.31	50.75	47.56	48.83	49.71	48.6

* Source: J. Reagan (1984) and 1982 NCLAN Annual Report (Heck et al. 1983a).

** Mean seasonal 7-h/day O_3 concentration, 6 months (April - September).

In the absence of any consistent pattern, the 5-year average was selected as a point of comparison with the 1980 values.

The only exception to this direct application of the Kriged seasonal data pertains to ozone levels used for winter wheat, which is grown in the winter period when ozone levels are typically less than observed in the April-September period. To approximate these lower winter levels, the April values for each region are used as the base ozone levels for use with the winter wheat response functions. These April values may be slightly higher than ambient winter season averages, but April is the period of greatest growth for winter wheat in most regions.

The second piece of ozone information needed to develop yield adjustments are the hypothetical ozone levels to be examined in the economic analysis. For the purposes of this assessment effort, these are identified as 10, 25, and 40% reductions in ozone from ambient (as portrayed in Table 5.2.4.2) and a 25% increase in ambient ozone. Each hypothetical ambient ozone level is then used in conjunction with the Weibull response functions for each crop to predict the yield changes associated with these changes in ambient ozone concentrations.

The 10 and 25% adjustments in ambient ozone are considered plausible changes, in that changes of this magnitude are encompassed in the temporal variability displayed in the 5-year ozone data set. Also, the 10 and 25% improvements in ozone levels are of policy importance in that these adjustments parallel changes in ambient ozone likely to be associated with alternative Federal SNAAQS of 0.10 and 0.08 ppm (not to be exceeded more than once per year). Assuming the imposition of a more strict Federal standard, the ambient seasonal 7-h concentrations should decline. If one assumes a log-normal distribution of ozone events over the season, then achieving a hypothetical Federal hourly standard of 0.08 would translate into a seasonal 7-h mean of about 0.04 ppm. Such an ambient ozone level is consistent with those achieved with the 25% ozone reduction scenario. Similarly, the 25% ozone increase results in ozone levels somewhat similar to what would be realized if a Federal SNAAQS of 0.14 ppm were just achieved.

The 40% ozone reduction is an extreme analysis in that such a reduction in ozone would bring actual ambient concentrations down to or below what is generally thought to be background or natural ozone levels (Heck et al., 1984a). Thus, the economic benefits measured in the 40% analysis may not be particularly relevant from a policy standpoint. It does, however, represent the maximum benefits of ozone control, assuming all anthropogenic sources of ozone precursors could be controlled.

5.2.4.3. Moisture stress - O_3 interactions

The NCLAN crop response function presented in Table 5.2.4.1. provide the mechanism for quantifying the biological link between ambient ozone levels and crop yield response. In addition to providing this quantitative information about plant response for use in economic assessments, the NCLAN crop experiments also provide information of a more qualitative nature concerning environmental stresses that may interact with ozone. Specifically, the possible interactive effects of ozone with water stress and with other pollutants (SO_2) have been addressed in a few experiments (see, for example, Heck et al., 1983a). While these experiments and the resultant data are not sufficient to adequately document and quantify such interactions, they provide some plausible grounds for modifying and perhaps bounding the economic estimates generated from the response information in Table 5.2.4.1.

The information on interactive stresses can suggest whether the NCLAN response functions (which are estimated holding other stresses constant) over- or under-state the real or "true" effect of ozone on commercially grown crops. While some of these observations are limited to discussion in qualitative terms, a few quantitative statements are possible for moisture stress, based on cotton and soybean experiments performed in 1982 and 1983. These observations, in combination with preliminary ozone-water stress simulations available from an NCLAN crop yield-soil moisture stress model, can quantify the link between ozone effects and water stress. This quantitative information is the basis of a moisture stress analysis which is defined as Analysis V. The soil moisture model and associated assumptions are used to derive the quantitative adjustment factors.

Using such quantitative information, the potential difference in ozone effects between sub-optimal and adequately irrigated crops can be compared. This differential for varying degrees of water stress can then be used to modify the yield adjustments based ozone-response data from well-watered fields.

Two types of information are needed to incorporate the effects of drought stress into the ozone assessment. First, information on the spatial distribution of rainfall in the U.S. is required to gauge the extent and severity of drought for a particular growing season. Given that summer rainfall patterns associated with continental climate zones tend to vary even within a relatively small topographical area, detailed spatial resolution in rainfall data is desirable. In this analysis, rainfall as measured on a state-by-state basis for 1980 serve to suggest the potential for drought stress.

A second piece of information is needed to translate the deviations from normal rainfall into drought stress yield reductions. This information is derived from studies by Thompson (1969, 1970) for corn and soybean yields in the Corn Belt. Specifically, regression equations are derived from Thompson's results that predict percent yield reduction for these crops associated with deviations in July precipitation. The effects across the two crops are averaged to arrive at a surrogate crop drought stress yield reduction. This reduction is then used in combination with the ozone-water stress trade-off curve to obtain an adjustment factor to be applied to the fully watered NCLAN response functions as used in the previous analyses.

A number of points need to be made concerning this procedure and the resultant adjustment factors. The drought stress procedure attempts to key on those states where crops are typically not irrigated. Thus, only states in the eastern half of the U.S. are included. Some states in this set, however, do feature a percentage of irrigated acreage. An attempt is made to account for states with both irrigated and non-irrigated acreage (Nebraska, Oklahoma, Kansas, Texas and Arkansas) by reducing the drought effect by the percentage of irrigated acreage. Second, the adjustment factor is based on the averaged response of corn and soybeans. It is assumed that this drought-yield relationship holds for all the crops in the assessment. While corn and soybeans are the dominant crops in the assessment, the use of this average may not accurately portray the response of other crops. Finally, the adjustment factors are based on a crop-yield soil moisture model not previously used for the purpose of explicitly analyzing ozone-water stress interactions. As noted above, the primary purpose of the analysis is to suggest the importance of accounting for moisture-stress and other interactions in economic assessments of environmental stress.

In addition to these data and assumptions concerning the biological and meterological basis for this economic assessment, other data and assumptions are also of importance. These concern the farm and sectoral level economic models used to generate the assessment. It should be noted that the economic model (its parameters, variables, and conceptual-analytical assumptions) has an important effect on the output of the assessment. Thus, at least three general sources of variability in the forthcoming economic estimates need to be recognized -- the biological, meterological and economic components of the assessment framework.

SECTION 6

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